THE 2,4-ETHANO- and 2,4-ETHENO-3-ALKOXY-TRIS-HOMOCYCLOPROPENYL CATIONS, ORIENTATION AND STEREOCHEMISTRY OF NUCLEOPHILE CAPTURE

By

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DEDICATION

To My Parents

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Abstract of Dissertation Presented to the Graduate Council of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

THE 2,4-ETHANO- and 2,4-ETHENO-3-ALKOXY-TRIS-HOMOCYCLOPROPENYL CATIONS, ORIENTATION AND STEREOCHEMISTRY OF NUCLEOPHILE CAPTURE

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Chairman: Dr. Merle Battiste
Major Department: Chemistry

Solvolyses of *endo,anti*-tricyclo[3.2.1.$0^{2,4}$]octanyl derivatives, i.e., hydrogen, vinyl, and *p*-anisyl substitution at the bridge C_8 position, have been shown to afford rearranged products (*endo* C_2 or C_4 attack) almost exclusively (>99%). Concentration of positive charge at the C_2 and C_4 positions of the respective intermediate tris-homocyclopropenyl cations might be an explanation; an alternative view stresses the importance of strain relief in the transition state for solvent capture of the non-classical cations.

In contrast to the above results, acidic hydrolysis of 8,8-dimethoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]octane (I) yields the expected ketone II with no evidence for the formation of a rearranged hydroxyether. This suggests that the charge stabilizing ability of the methoxyl group at the bridge carbon may well be overwhelming the skeletal bias of the transition state for solvent capture.

Saturated ketal I was treated with dichloroaluminum hydride to yield the *syn*-methyl ether exclusive of its *anti* epimer. Under the same reaction conditions, the unsaturated ketal, 8,8-dimethoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene (III), gave the unsaturated *syn*-methyl ether IV as the major product along with 1-methoxy-*endo*-6-chlorotricyclo[3.3.0.$0^{2,8}$]-oct-3-ene (V) as a minor product. Traces of *endo*-6-methoxy- and *endo*-6-chlorotricyclo[3.3.0.$0^{2,8}$]oct-3-enes,(VI) and (VII), were also detected. The trace components are attributed to the intermediacy of unsaturated *anti*-methyl ether VIII as evidenced by its authentic synthesis and subsequent exposure to the reactions conditions. The predominance of bridge C_8 *anti* hydride attack and formation of *endo* unsaturated rearranged chloride V argue strongly for the intermediacy of a delocalized system with charge concentrated at C_8 due to methoxyl stabilization. The transient formation of the unsaturated *anti* methyl-ether VIII could result from hydride attack upon a bis-homocyclopropenyl cation, whose mode of formation has several potential routes.

Use of an 8:1 molar ratio of the aluminum chloride/lithium aluminum hydride reagent with the respective saturated and unsaturated methyl ketals I and III produced good yields of the saturated and unsaturated rearranged methoxy chlorides IX and V, both of which were solvolyzed at 100° in aqueous ethanol. For the unsaturated chloride V, the major product, cycloheptatriene, and a mixed ethoxy-methoxy ketal fraction of the original tricyclo[3.2.1.$0^{2,4}$]octenyl structure were

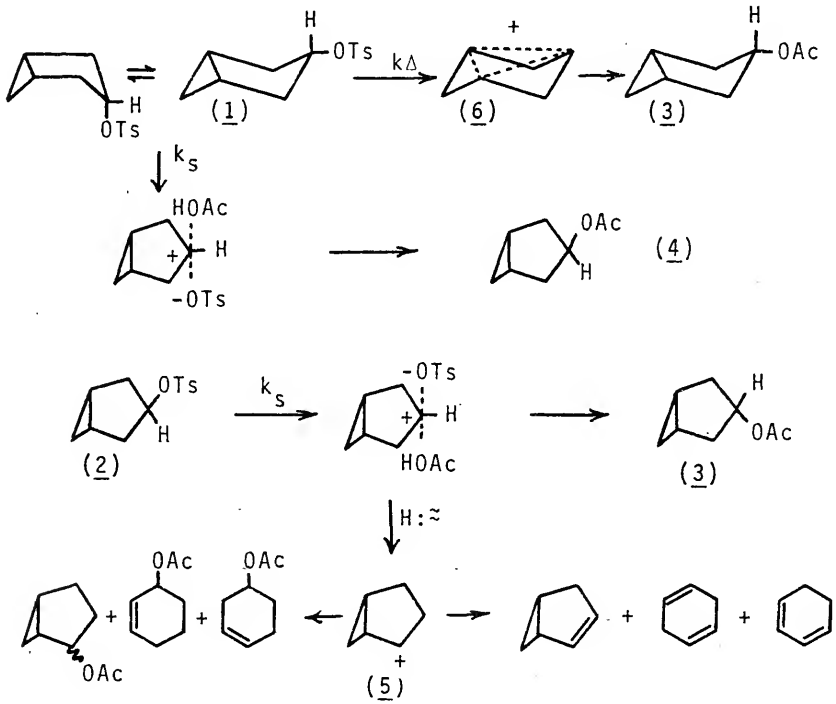
isolated. Cycloheptatriene is the expected product from the well-known decarbonylation of the unsaturated ketone. According to PMR analysis the mixed ketal fraction consisted of 89% *anti*-ethoxy-*syn*-methoxy unsaturated ketal and 11% *anti*-methoxy-*syn*-ethoxy ketal. Solvolysis of the saturated chloride IX in aqueous ethanol produced the saturated ketone II as the major product with a mixed ketal fraction consisting of 96% *anti*-ethoxy-*syn*-methoxy ketal and 4% *anti*-methoxy-*syn* ethoxy ketal.

The results obtained strongly indicate that the same cations are being generated from the respective reactions of the saturated and unsaturated ketals I and III with dichloroaluminum hydride and aqueous acid, as well as in the solvolyses of the saturated and unsaturated rearranged methoxy chlorides IX and V. The electronic structure of these ions has now been radically altered with respect to the parent ions in that positive charge delocalization is not as extensive, giving a more localized or concentrated charge at the methoxyl bridge carbon. The cyclopropyl delocalization may even have been weakened to the point where nucleophiles are able to penetrate and attack the bridge from the *syn* as well as *anti* face of the bridge. Thus an electronic effect, and not steric bias, is the overwhelming factor in determining the orientation and stereochemistry of solvent or nucleophilic attack on the 2,4-ethano- or 2,4-etheno-3-alkoxy-tris-homocyclopropenium cations.

CHAPTER I

Introduction

The neighboring group reactivity of the cyclopropyl moiety has received intense investigation and documentation in the chemical literature.[1] One of the more dynamic directions of these studies has involved the assistance to ionization rendered by the cyclopropyl carbon-carbon *sigma* (edge) bond at a remote site relative to the cyclopropyl group.



In the vanguard of the early cyclopropyl studies was work carried out by Winstein and his reports[2] of the results of solvolytic studies involving *cis*- and *trans*-3-bicyclo-[3.1.0]hexyl toluenesulfonates, (1) and (2).

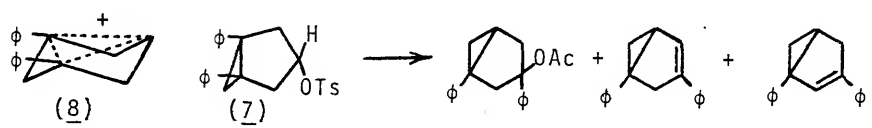
The *cis*-3-tosylate (1), exhibited essentially complete retention of configuration under acetolysis with the nearly exclusive formation (99%) of *cis*-3-acetate (3). *Trans*-3-acetate (4) amounted to less than 1% of the reaction product. *Trans*-3-tosylate (2), in contrast, produced a complex mixture of compounds, 54% of which consisted of *cis*-3-acetate (3), an inverted, solvent-assisted ionization product resulting from the shielding by the departing anion. The remaining components, i.e. olefins and acetates, apparently were derived from the competitive formation of cation (5), which would have orginated via hydride transfer. The facts that *cis*-3-tosylate (1) solvolyzed ca. thirty-five times faster than the *trans*-3-tosylate (2), and only the *cis*-3-tosylate (1) exhibited a special salt effect, prompted Winstein to state that the *cis*-3-tosylate (1) was ionizing to form the homoaromatic[3a-c] 3-bicyclo[3.1.0]hexyl cation (6), a non-classical tris-homocyclopropenyl[3] cation (two *sigma* electrons delocalized over three equi-distant centers).

Both the *cis*- and *trans*-3-bicyclo[3.1.0]hexyl tosylates, (1) and (2), were deuterated at the C_3 position[2a,d,e] and solvolyzed under the original conditions. It was found that in the case of *cis*-3-tosylate (1), the deuterium label had completely scrambled in the C_1, C_3, C_5 positions of the *cis*-3-acetate product. There was essentially no scrambling

observed with the correspondingly deuterated *trans*-3-tosylate under the same conditions. This was interpreted[2a,d,e] as powerful evidence for the intermediacy of the tris-homocyclopropenyl cation (6).

Corey studied[4] the deamination of *cis*- and *trans*-3-bicyclo[3.1.0]hexylamine and found a complex product mixture for both amines consisting of epimeric 2- and 3-alcohols. There was only partial scrambling of a deuterium label for the *cis*-3-amine and essentially no scrambling for the *trans*-3-amine deamination. Corey felt that both amines produced classical ions which did not leak over to the homoaromatic species, possibly because deamination produces a vibrationally excited cation. A number of other workers have also expressed[5] the viewpoint that the diazonium ion is a poor model for solvolytic work.

In an accompanying paper,[6] Corey acetolyzed 1,5-diphenyl-*cis*-3-bicyclo[3.1.0]hexyl toluenesulfonate (7), expecting a rate increase from phenyl stabilization if the tris-homocyclopropenyl cation (8) was indeed generated. In fact, he observed a small rate retardation; the products detected,



(8) (7)

however, were totally rearranged. To explain his results and Winstein's, Corey suggested equilibrating classical ions (9), the equilibration being the reason for deuterium scrambling and a "weak interaction involving the vacant

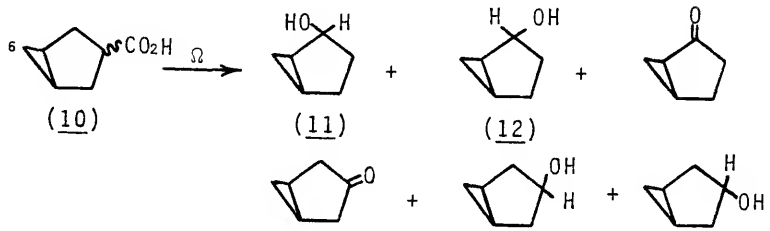
(9)

orbital at C_3 and the loose electrons of the three-membered ring"[6] responsible for the stereospecificity of *cis*-3-bicyclo[3.1.0]hexyl tosylate (1).

Winstein has countered with the point that ionization with assistance from the cyclopropyl ring in the *cis*-3-tosylate (1) should occur only in the chair conformation of the bicyclohexyl ring, and there is evidence[2e,7,8] that bicyclohexyl derivatives have a marked preference for the boat conformation. As a consequence, there would be, at any one time, a proportionately small number of molecules in the system capable of employing the anchimeric assistance of the cyclopropane ring. The titremetric rate constant for the *cis*-3-tosylate (1) should be well below any valid estimate for the degree of anchimeric assistance. Winstein felt[2e] the diphenyl derivative (7) would be shifted even more into the boat conformation and therefore would be expected to ionize in essentially a classical manner. Extending this hypothesis further, generation of a positive charge at the C_3 position of the bicyclo[3.1.0]hexyl system and its derivatives by processes which do not depend upon anchimeric assistance would, by very large odds, take place in the boat conformation. One would anticipate the classical ion formation to be a higher energy process than the non-classical solvolytic process, and this, coupled with the high probability for boat form

involvement, would result in a very reactive ion that may have little opportunity to leak into the tris-homocyclopropenium manifold.

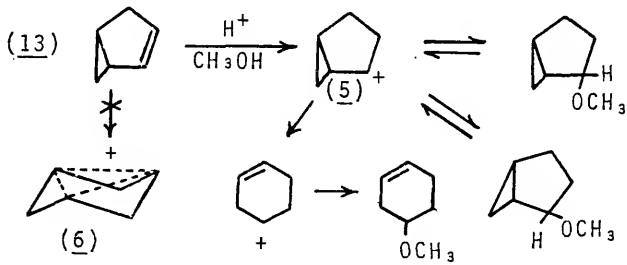
Gassman attempted[9] the electroytic oxidative decarboxylation of *cis*- and *trans*-bicyclo[3.1.0]hexane-3-carboxylic acids (10) and determined the predominant products to be the *cis*- and *trans*-2-bicyclo[3.1.0]hexanols, (11) and (12).



(10) (11) (12)

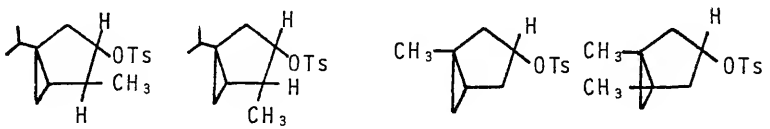
Deuterium labeling at C_6 produced no scrambling. Both Gassman and Winstein agreed that the reaction on the electrode surface was too complex to allow a valid mechanistic comparison with the solvolysis of the 3-bicyclo[3.1.0]hexyl tosylates (1) and (2).

Freeman[7] attempted to generate a carbonium ion at the C_3 position of the bicyclo[3.1.0]hexyl system via the acid catalyzed addition of methanol to 2-bicyclo[3.1.0]hexene (13), anticipating the generation of Winstein's cation (6).

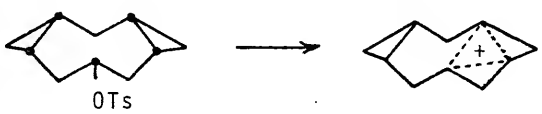


All the products identified, however, were considered to be derivatives of the bicyclohex-2-yl cation (5), which is a cyclopropylcarbinyl cation that Winstein considers[2e] to be more stable than the tris-homocyclopropenyl cation (6).

Much of the solvolytic work following Winstein's original work[2] generally added to the weight of evidence for the existance of the tris-homocyclopropenyl cation as a viable intermediate. Norin subjected[10] the optically active thujyl tosylates, (14) and (15), to acetolysis and found they yielded their respective racemic acetates, paralleling Winstein's deuterium labeling studies in the parent bicyclohexyl series. As expected, the rates of (14) and (15) were greater than their *trans* analogs. Solvolyses of the mono- and dimethyl substituted bicyclohexyl tosylates, (16) and (17), have been recognized[2e,3a] as examples for generation of tris-homocyclopropenyl species.



(14) (15) (16) (17)

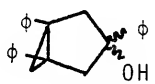


(18) (19)

Of the numerous options for the tricyclodecyl tosylate (18) during solvolysis, Hückel LCAO-MO calculations predicted[11] the development of the tris-homocyclopropenium cation (19) as the intermediate. Again, by means of kinetics,

deuterium labeling, product identification and stereochemistry, the prediction was verified.[11]

Further evidence for the homoaromatic nature of the 3-bicyclo[3.1.0]hexyl cation (6) has been formulated by determining[12] the activation volumes from the solvolyses of the *cis*- and *trans*-3-bicyclo[3.1.0]hexyl tosylates (1) and (2). The *trans*-3-tosylate (2) exhibited an activation volume (-17.4 cc/mole) in line with cyclopentyl- and cyclohexyl tosylate. The *cis*-3-tosylate (1), however, had a volume of activation of -13.9 cc/mole. The authors viewed the difference as indicative of a diffuse charge, e.g. a non-classical ion, in the *cis*-3-tosylate (1) solvolysis transition state, which supports the concept of the intermediacy of the tris-homocyclopropenyl cation (6).



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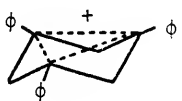
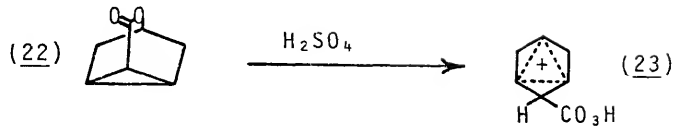


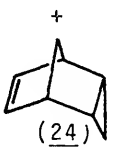
(21)

Broser and Rahn reacted[13] the epimeric alcohols (20) with boron trifluoride in polar solvents to yield deeply colored solutions which were unaffected by oxygen. The introduction of tropilidene gave a 51% yield of tropylium hydroxyfluoroborate. On the basis of direct observation via NMR, IR, and visible spectra, the authors favor the formation of the non-classical ion (21).

Sauers, in an earlier study,[14] reported the NMR spectrum of lactone (22) in concentrated sulfuric acid. It was Sauers' view that the tris-homocyclopropenyl cationic derivative (23) was a stable entity in this medium.



The weight of kinetic evidence for the existence of the tris-homocyclopropenyl cation at this point was certainly not overwhelming, the maximum reported[10] rate enhancement being ca. 922. The experimental results fell short of the theoretical predictions and calculations previously published. As a result of early LACO calculations, Winstein stated[3b] "that the 3-bicyclo[3.1.0]hexyl cation prefers the non-classical tris-homocyclopropenyl structure to a classical one." Extended Hückel calculations by Hoffmann predicted[15] that Corey's "almost classical" non-classical ion (9) would be less stable than the classical ion on a planar five-membered ring. Remarkably, calculations did predict a deep minimum in energy of ca. 1 eV for the symmetrical tris-homocyclopropenyl cation (6).

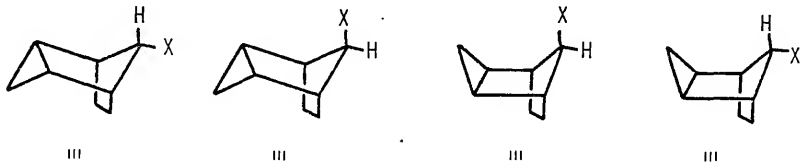


(24)

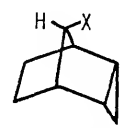
Hoffman also reported[15] calculations on the hypothetical cation (24), which indicated an unsymmetrical double minimum resembling the 7-norbornadienyl cation calculations, except the energy well was deeper as bending of the bridge occurred toward the cyclopropyl group as compared to bending toward the double bond.

The consensus was that the full potential of the homo-conjugative ability of the cyclopropyl group had yet to be

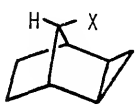
realized because of the geometric shortcomings of the various systems studied. The added "p" character of the cyclopropyl carbon-carbon *sigma* bond and the general "bent bond" nature of the orbitals[16] appeared to require a rather exacting alignment for efficient overlap with the developing "p" orbital of the ionization center during the initial stages of cation formation.



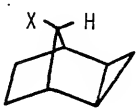
endo, anti≡ *cis*-chair (25)



endo, syn≡ *trans*-chair (26)



exo, syn≡ *cis*-boat (27)

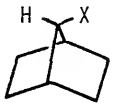


exo, anti≡ *trans*-boat (28)

It occurred to a number of researchers that if the C_2 and C_4 positions of the chair and boat conformations of both the *cis*- and *trans*-3-bicyclo[3.1.0]hexanols were connected by an ethano bridge, the four possible combinations could effectively be frozen out, allowing an efficient probe of the reactivity of the cyclopropyl group while holding the stereochemistry under virtually complete scrutiny.

An added advantage to this series of tricyclo[3.2.1.$0^{2,4}$]-octan-8-ols, (25)-OH through (28)-OH, was the fact that a direct comparison could be made to the reactivity of the cyclopropyl group versus the double bond.

Earlier, Winstein et al.[17] solvolyzed both the *syn*- and *anti*-7-norbornenyl tosylates, (30)-OTs and (31)-OTs, and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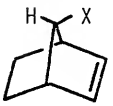
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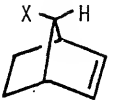
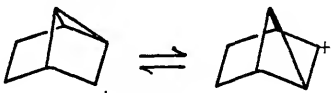

(31)

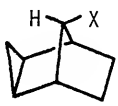
relative rate	1	10^4	10^{11}

compared their rates to that of the saturated norbornyl tosylate (29)-OTs. The large rate enhancement for the *anti*-tosylate (31)-OTs has been explained[17,18] by Winstein in terms of a non-classical bis-homocyclopropenium intermediate (32), although others have strongly endorsed[19] the concept of


(32)


(33)

rapidly equilibrating ions (33).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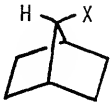
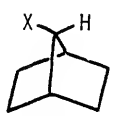

(29)

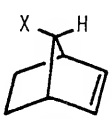
Pincock first reported[20] the synthesis of the *p*-bromobenzenesulfonate derviative of *exo-anti*-tricyclo[3.2.1.$0^{2,4}$]octan-8-ol, (28)-OBs, and found that it underwent acetolysis at a rate 2.7 times slower than the corresponding 7-norbornyl brosylate (29)-OBs. It was felt that the slight rate retardation was due to the steric interference by the *exo*-methylene group with the solvation occurring at the backside of the leaving brosylate group at C_8. A possible negative inductive

effect of the cyclopropyl group was also considered. The primary observation, that there was no unusual effect of the cyclopropyl group in the *exo* psoition, was attributed to the fact that the cyclopropyl *sigma* orbitals are directed down and away from the reaction site at the C_8 position. Pincock anticipated that this would not be the case for the *endo* isomer (25).



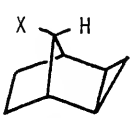
(29)

k_{rel} 1



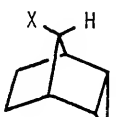
(31)

10^{11}



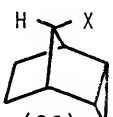
(28)

.4



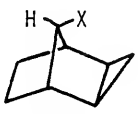
(25)

10^{14-15}



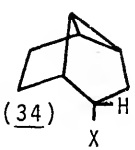
(26)

15



(27)

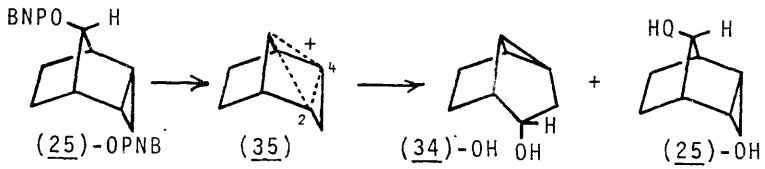
10^4



(34)

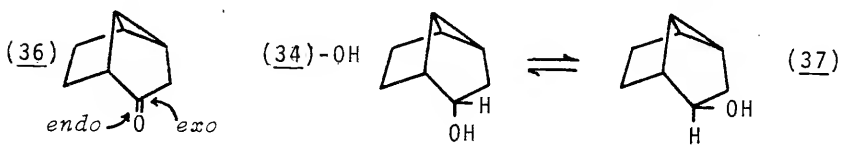
The three laboratories of Pincock,[21a] Battiste,[21a] and Tanida[21b,c] issued the simultaneous report of the synthesis of the *endo-anti*- and *endo-syn*-8-tricyclo[3.2.1.$0^{2,4}$]octanols (25)-OH and (26)-OH. Solvolysis of (25)-OPNB produced a rate enhancement factor of ca. 10^{14} relative to the *exo-anti* system (28) and the norbornyl derivative (29), a "new record for participation"[22b]. With 70% aqueous dioxane as the solvent, only two major products were detected,[22] the rearranged *endo*-4-tricyclo[3.3.0.$0^{2,4}$]octanol (34)-OH and its *p*-nitrobenzoate

ester (34)-OPNB. Tanida also reported[21c] the formation of a trace (0.1%) amount of the retained alcohol (25)-OH. The overwhelming formation of rearranged products implies that



most of the positive charge resides on the C_2, C_4 positions of the intermediate, analogous to the charge distribution in the ion generated from the *anti*-norbornenyl derivative (31).[23]

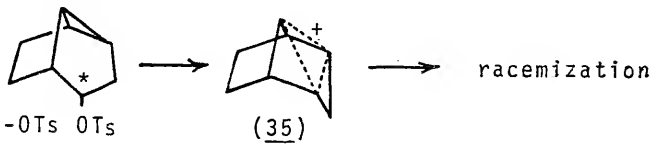
A very important point is that ion pair return or solvent capture occurs stereospecifically at C_2 and C_4 from the *endo*-direction only, in sharp contrast to the observed[21c,22] reduction of ketone (36) with lithium aluminum hydride which gave exclusive *exo* attack to yield *endo*-alcohol (34)-OH. Equilibration experiments have reportedly produced a mixture



of 38% *endo* alcohol (34)-OH and 62% *exo*-alcohol (37). Thus, it would appear that *exo*-alcohol (37) is preferred both kinetically and thermodynamically. It is worth noting that despite an environment that is 67 mole percent water, the intermediate cation is stable and long-lived enough to permit the internal return of the *p*-nitrobenzoate anion, i.e.,

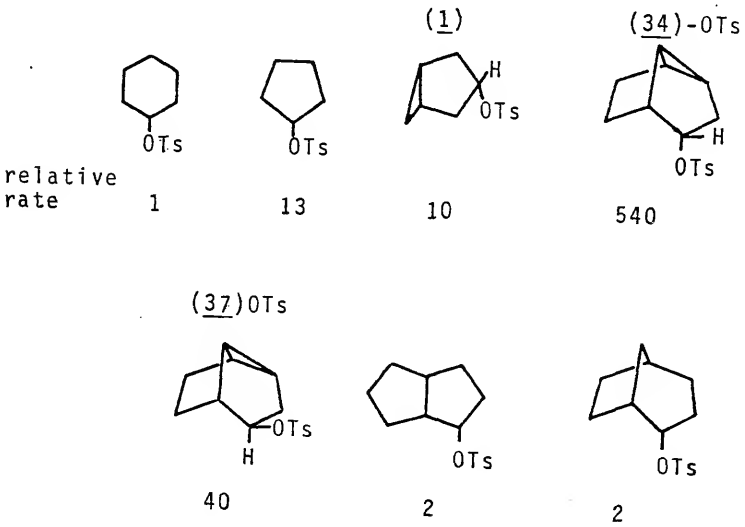
time enough for the anion to approach the cation from another direction.[22] These facts are uniquely explained by the invocation of the non-classical 2,4-ethano-tris-homocyclopropenyl cation (35) as the intermediate.

Tanida prepared[21c] an optically active sample of the rearranged alcohol (34)-OH, and acetolyzed its tosylate



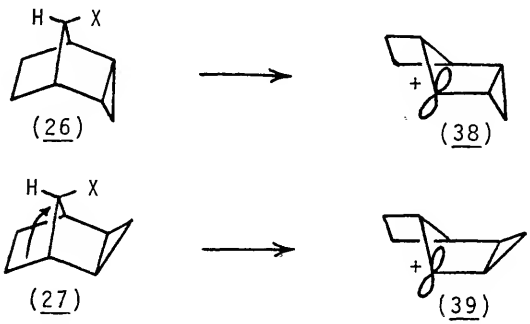
(34)-OTs OTs (35)

(34)-OTs. The rate of racemization was 3.2 times faster than the rate of acid formation, strongly indicating the occurance of internal return. Ultimately complete racemization occurred, and the existance of any potential hydride shift was eliminated via deuterium labeling. A comparison



of the solvolysis rate of (34)-OTs with a number of appropriate compounds[21c] demonstrated that the rearranged derivative is still very reactive. Tanida was compelled to state that the tris-homocyclopropenyl cation (35) is the simplest and most economical intermediate to invoke.

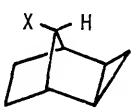
The rate of acetolysis of *endo-syn* brosylate (26)-OBs is a little over ten times that of 7-norbornyl brosylate and gives a complex product mixture.[21,22]



(26) (38)

(27) (39)

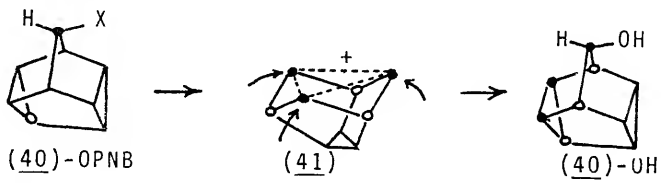
In contrast, *exo-syn* brosylate (27)-OBs produces a relative rate of 10^4. The methylene group from the *exo* cyclopropyl ring could sterically aid the departure of the brosylate anion.[22,24] Another possible factor could be the concerted shift with ionization of the C_1 to C_7 bond to the C_8 position to produce a stabilized cyclopropylcarbinyl cation (39). There would not be initial stabilization in the cation (38) produced by the analogous process for (26)-OBs since the orbitals would not be aligned in parallel.[22]



(28)

The sluggishness of *exo-anti* (28) can be attributed to its lack of options, i.e., it cannot undergo the C_1, C_7 to C_8 bond rearrangement to the cyclopropylcarbinyl cation, and, of course, the rigid geometry prevents the proper orientation of the cyclopropyl orbitals for participation.[22]

Coates synthesized[25] pentacyclo[4.3.0.$0^{2,4}$.$0^{3,8}$.$0^{5,7}$]-nonan-9-ol, (40)-OH, and found a rate enhancement of 10^{10}-10^{12} relative to 7-norbornyl derivatives. Overall strain relief

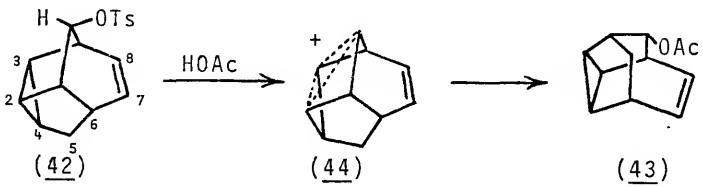


(40)-OPNB (41) (40)-OH

cannot be a driving force since a homocyclopropylcarbinyl rearrangement produces a structure identical with the original. The only hydrolysis product, in the presence of 2,6-lutidine, was determined to be the parent alcohol (40)-OH. These facts, coupled with the results of deuterium labeling, were interpreted in terms of the threefold symmetric tris-homocyclopropenyl cation intermediate (41). Apparently any secondary rearrangement is unable to compete with the attack of water.[25] Coates suggested that the greater reactivity (ca. 80) of the tricyclic p-nitrobenzoate (25)-OPNB relative to the pentacyclic p-nitrobenzoate (40)-OBNB could be attributed to some strain relief in the solvolytic transition state and/or a somewhat less favorable orientation of the *anti*-cyclopropyl group in (40)-OPNB due to the bond connecting the two three-membered rings. Nevertheless, Coates argued that the

overwhelming bulk of the driving force for both (25)-OPNB and (40)-OPNB arose from the anchimeric assistance of the *anti*-cyclopropyl ring to form the symmetrical tris-homocyclopropenyl cations (35) and (41).

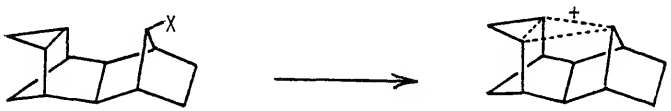
Ellen and Klumpp[26] acetolyzed the interesting compound, *exo*-tetracyclo[4.4.0.$0^{2,4}$.$0^{3,9}$] dec-7-en-10-yl tosylate (42)-OTs, and found exclusive attack at C_8 yielding only *exo*-tetracyclo-[4.3.1.$0^{3,6}$.$0^{7,9}$]dec-4-en-2-yl acetate (43)-OAc. Conversion



(42) (44) (43)

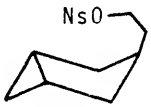
(45) (46)

of (43)-OAc into its tosylate (43)-OTs, followed by acetolysis, regenerated (43)-OAc as the sole product. While the authors felt that the tris-homocyclopropenyl cation (44) was involved as the intermediate, they saw a high contribution from (45) in which the positive charge is concentrated at C_3, resulting in less strain than cations having the charge bulk on C_2 or C_{10}. The possibility of homoallylic stabilization, (46), was also recognized.

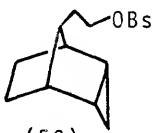


(47) (48)

Battiste and Winstein[27] acetolyzed the tris-methano-naphthalene brosylate (47)-OBS, and found evidence for considerable (ca. 10^5- 10^8) cyclopropyl participation, proposing the initial formation of the non-classical intermediate (48). Product analysis revealed the absence of (47)-OAc or any rearranged or unrearranged brosylate derivatives. The authors felt the cyclopropyl group, and therefore its *sigma* orbitals, are directed toward the cavity between the two bridges, decreasing the initial degree of orbital overlap with the developing positive center and resulting in some moderation of the relative rate.



(49)

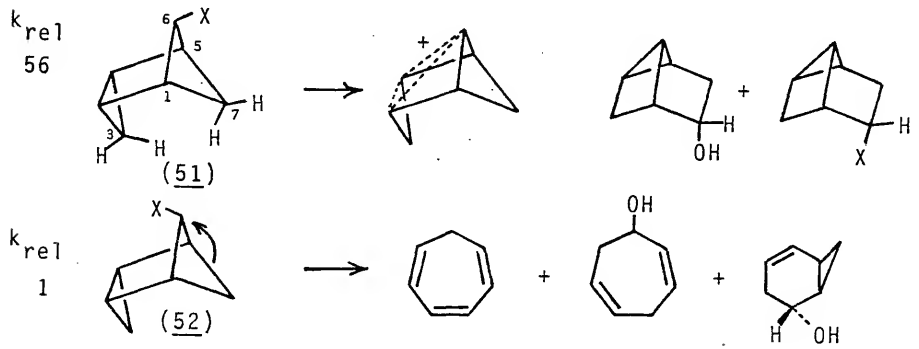


(50)

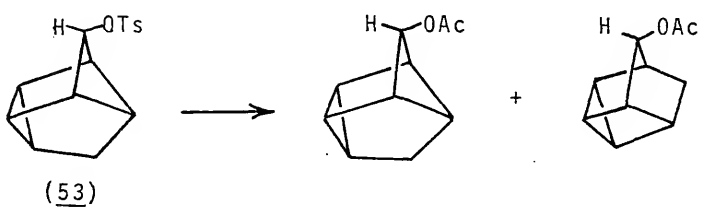
As a further example of the rather precise orientation requirements of the cyclopropyl ring needed for assistance to occur, the solvolysis[28] of 2-(*trans*-3-bicyclo[3.1.0])ethyl p-nitrobenzenesulfonate (49) gave no kinetic or product evidence whatsoever for participation. Tanida's study[29] of β-(tricyclo[3.2.1.$0^{2,4}$]oct-*syn*-8-yl) ethyl p-bromobenzene-sulfonate (50) gave questionable evidence for cyclopropyl participation. The small rate factor of three for (50) relative to its *anti*-analog, was suggested to be due, at least in part, to repulsive hydrogen interactions in the transition state.

The solvolyses of derivatives of *exo*- and *endo-anti*-tricyclo[3.1.1.$0^{2,4}$]heptan-6-ol, (51) and (52), were studied[30]

to provide additional insight into the geometrical requirements for participation of the cyclopropyl group. Interestingly, it was determined that (51)-OPNB was only fifty-six times faster than (52)-OPNB, although (51)-OPNB yielded the two

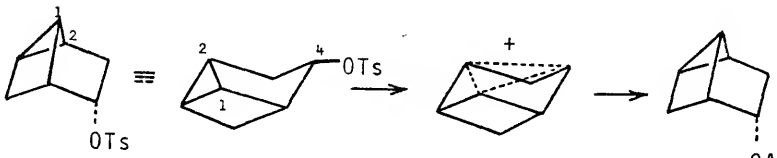


rearranged products expected from a tris-homocyclopropenyl cation intermediate while (52)-OPNB produced an olefinic mixture. It was concluded[30b] that both compounds were solvolyzing with considerable (though different) neighboring group assistance. The fact that (51)-OPNB was solvolyzing at a rate ca. ten times slower than *endo-anti*-8-tricyclo[3.2.1.$0^{2,4}$]-octanyl p-nitrobenzoate (25)-OPNB was attributed through X-ray studies to significant geometrical distortion caused by hydrogen interaction at C_3 and C_7.



Coates subjected[31] the *exo*-tetracyclo[3.3.0.$0^{3,6}$.$0^{2,8}$] oct-4-yl tosylate (53) to acetolysis and detected the two expected acetate products. Kinetic studies demonstrated a rate acceleration from anchimeric assistance of ca. 10^9. Coates concluded that the methylene bridge at C_7 directs the cyclopropyl orbitals away from the site of ionization.

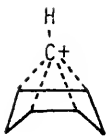
Lustgarten reported[32] the acetolysis of the *endo*- rearranged tosylate (54)-OTS, giving the *endo*-rearranged acetate (54)-OAc as the sole product. It was his view that (54)-OTs



(54)-OTs (55) (54)-OAc

ionized with assistance from the C_1-C_2 bond to give tris-homocyclopropenyl cation (55), the same intermediate ion derived from 51-OTs. A deuterium label at C_4 gave an equal distribution of deuterium on C_2 and C_4 after solvolysis, however only half of the original label was accounted for at these two positions, compelling Lustgarten to conclude that the full nature of the intermediate cation had yet to be determined.

In separate papers, Masamune[33] and Hart[34] detailed direct spectral evidence for the existance of the symmetric pyramidal delocalized cations, (56) and (57) respectively. Both cations accounted for the deuterium label discrepancy previously mentioned, and the higher symmetry was predicted by Stohrer



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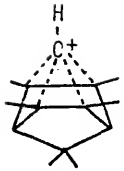


(57)

and Hoffmann[35] to be relatively stable.

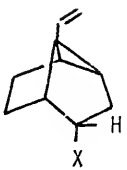
(58)

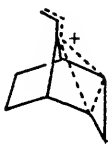
(59)

(60)

k_{rel} 622 1 26.2

(61)





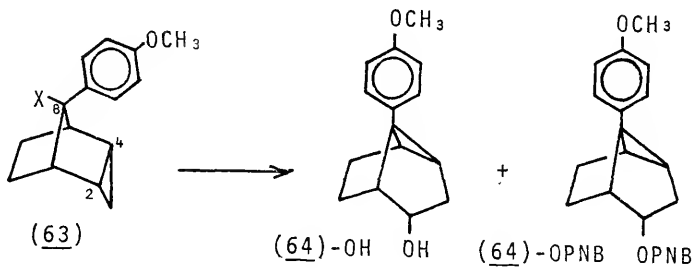
(62)

Sargent probed[36] the ability of a cyclopropyl moiety to function as a remote, nucleophilic neighboring group by interacting with a carbon-carbon double bond which is itself providing a source of electronic stabilization for a developing cation. Solvolysis of the tricyclic dinitrobenzoate (58)-ODNB demonstrated a significant rate acceleration (k_{rel}= 622) relative to the allylic dinitrobenzoate (59)-ODNB, which lacks an internal remote nucleophile. The ester (58)-ODNB was also faster than the double bond analog (60)-ODNB by a factor of 23.6.

Product studies from the hydrolysis of (58)-ODNB indicated only two rearranged products, *endo*-alcohol (61)-OH and *endo*-dinitrobenzoate (61)-ODNB. The striking simplicity and

and stereospecificity of the products strongly suggest the intermediacy of an unusually stable cation. Both solvent and dinitrobenzoate anion attack exclusively from the more hindered direction at a position four bonds (ca. 4Å) away from the initial site of ionization. The longevity of this cation is further demonstrated by the fact that the weakly nucleophilic dinitrobenzoate anion is able to compete with water in the product forming sequence. As a result of these observations, Sargent favored[36] the intermediacy of the non-classical cation (62).

From the solvolyses of *syn*-7-*p*-methoxyphenyl-*anti*-7-norbornenyl *p*-nitrobenzoate and its saturated analog, Gassman[37] determined that the *p*-anisyl group was capable of exerting a leveling effect of ca. 3×10^{10} with regard to neighboring group participation. A *p*-anisyl group was substituted at the

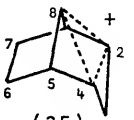


(63) (64)-OH OH (64)-OPNB OPNB

syn-C_8 position in the *endo-anti*-8-tricyclo[3.2.1.$0^{2,4}$]octanol system giving (63)-OH. Treatment of (63)-OH with acid yielded the rearranged alcohol (64)-OH as did the hydrolysis of the *p*-nitrobenzoate derivative (63)-OPNB. The hydrolysis of (63)-OPNB also yielded the internal return product, the rearranged *p*-nitrobenzoate (64)-OPNB. Gassman had predicted

a rate acceleration by the cyclopropyl group of 3 x 10^3 over and above the leveling of the *p*-anisyl moiety, and observed a value of 3.8 x 10^3. It was emphatically noted that even though a cation at C_8 would be tertiary and stabilized by the *p*-anisyl group, the bulk of the charge resides on C_2 as determined by the formation of rearranged products, i.e., the cyclopropyl ring controlled product formation.

As has been seen up to this point, the generation of the 2,4-ethano-tris-homocyclopropenyl cation (35) has resulted overwhelmingly in product formation at the *endo* C_2 and C_4 positions, suggesting, perhaps, that the bulk of positive charge in the intermediate resides at these positions as opposed to the bridge C_8 position.[22] Tanida calculated[21c] the ground state energy difference between the two alcoholic



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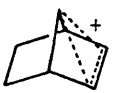


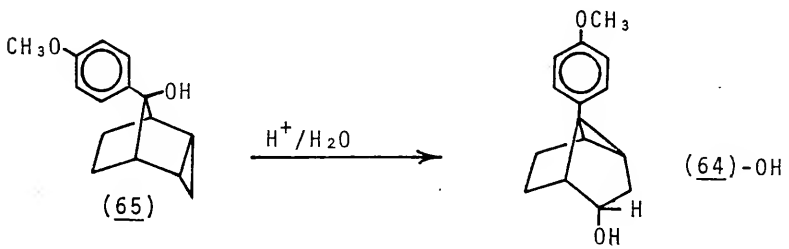
(32)

products of cation (35) based on a distribution of 99.9% (C_2, C_4 attack) for rearranged alcohol (34)-OH and 0.1% (C_8 attack) for retained alcohol (25)-OH. The resulting value of 12.1 kcal for $\Delta F°$ indicates a considerable amount of strain relief in the transformation to the rearranged alcohol (34)-OH.

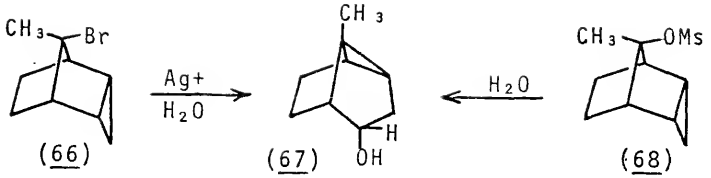
Pincock[22] pointed out the analogous charge distributions for both the tris-homo- (35) and bis-homo- (32) cations, and referenced Winstein's description of the 7-norbornenyl cation (32). The bridge carbon atom of cation (22) has "considerable

tendency to rehybridize from sp^2 toward sp^3. Such rehybridization increases the C_7 Coulomb integral as well as C_7-C_2 and C_7-C_3 orbital overlap. This leads to net stabilization of the bridged ion, and these very features of rehybridization at C_7 tend to diminish the charge on this atom."[23b]

As noted earlier, even substitution at C_8 with a vinyl group (formally causing the generation of an allylic cation upon ionization) and an anisyl group resulted in rearranged product upon solvolysis. Substitution of a cationic stabilizing group at the C_8 *anti* position along with a *syn* leaving group apparently allows leakage to the non-classical intermediate followed by nucleophilic capture to yield *endo* rearranged products. Thus, when Gassman treated the *syn*-



alcohol (65) with acid,[37] only rearranged alcohol (64)-OH was isolated. Baird and Reese[38] reacted the *anti*-methyl-*syn*-bromo tricycle (66) with Ag^+ and recovered only the rearranged

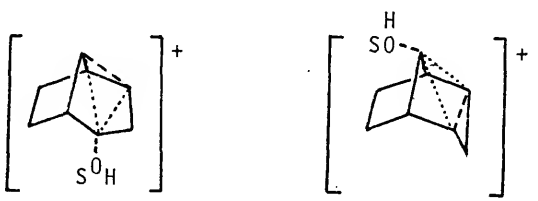


(66) (67) (68)

alcohol (67). Alcohol (67) was also the hydrolysis product of the *syn*-mesylate (68).

That there is little positive charge residing on the bridge C_8 position of the tris-homocyclopropenyl cation (35) is a conclusion which might be supported by the fact that substitution of various electron donating groups at C_8 had no effect on the products, i.e., only *endo* rearranged species were observed. This concept is feasible, but it seems more likely that there is a steric bias in the transition state of nucleophilic capture by cation (35).

Tanida's ground state energy calculations, which favored the rearranged alcohol (34)-OH over the retained alcohol (25)-OH by 12.1 kcal, should reflect the strain energy difference between the two possible transition states for solvent capture.

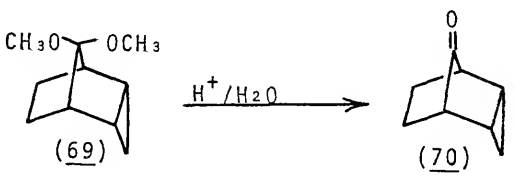


This being the case, the transition state energy barrier difference, paralleling the product alcohols, would be greater than zero and less than 12 kcal. The intensity of positive charge at the bridge C_8 of cation (35) could very well have

been increased by the substitution of the electron donating groups previously discussed, but to a degree insufficient to swamp out the steric bias of the transition state for capture of weak nucleophiles.

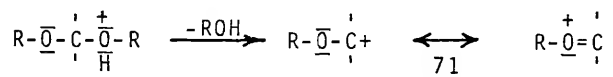
Considering this point, one could envision stronger electron donating groups at the bridge C_8 position tipping the balance of solvent capture in favor of charge over steric bias. As can be seen below, the methoxyl group appears to be just such an entity and it is consequently used in this investigation as a further probe into the balance between charge versus steric strain relief in the tris-homocyclopropenyl cation manifold.

Part of the synthetic scheme employed to prepare the alcohols (25)-OH and (26)-OH involves the acidic hydrolysis of the saturated ketal, 8,8-dimethoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]-octane (69). The only product reported[21a,22,39] by three different laboratories was ketone (70), *endo*-tricyclo[3.2.1.$0^{2,4}$]



(69) (70)

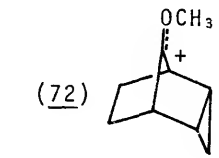
octan-8-one. It is generally assumed,[40] mechanistically,



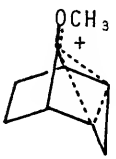
71

that the ease with which ketals suffer acidic hydrolysis is the result of resonance stabilization in the alkoxy carbonium ion intermediate (71).

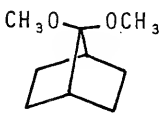
The formation of only ketone (70) from ketal (69), or more specifically the absence of rearranged products, leads one to question the existence of participation involving the cyclopropyl group. There appear to be two extremes as to the nature of the carbonium ion intermediate generated from (69): 1) essentially a classical oxo-carbonium ion (72), in which methoxy resonance stabilization of the positive charge at C_8 swamps out any energy need for cyclopropyl interaction 2) a non-classical methoxy-trishomocyclopropenyl cation (73) in which most of the positive charge resides on the bridge carbon C_8, despite considerable cyclopropyl involvement in charge stabilization.



(72)

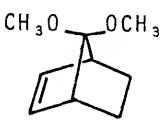


(73)



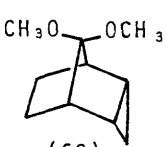
(74)

rel rate 1



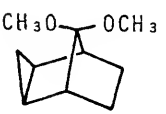
(75)

2.3



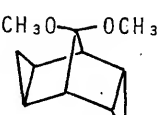
(69)

120



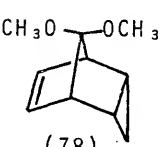
(76)

rel rate 18



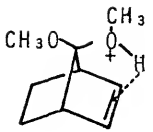
(77)

143



(78)

320



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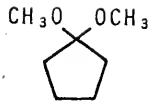


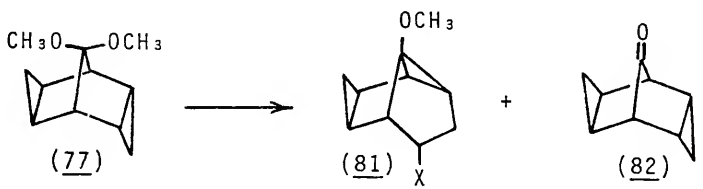
(80)

During the course of the research efforts reported in this text, the kinetics of the acidic hydrolyses of the above ketal series were revealed by Lamaty et al.[41] The rates of formation of the expected ketone products were monitered by means of the carbonyl ultraviolet absorption. The contrast between previous solvolytic studies of the respective alcoholic derivatives (rate acceleration up to 10^{14}) and the more subtle trends (rate acceleration ca. 10^{2}) observed for the hydrolysis of their ketal precursors is obvious. Apparently, the methoxyl group is capable of an even greater leveling effect than the *p*-anisyl group. Lamaty explained his results on the basis of the likely sites of protonation. It has been shown[42] that the alcohols *syn* with respect to the double bond or the cyclopropyl group exhibit considerable hydrogen bonding, the strongest interaction occurring in the olefin case. As an example of Lamaty's argument, the norbornenyl ketal (75) hydrolyzes only 2.3 times faster than the norbornyl ketal (74). Protonation of the *anti*-methoxyl group of (75) is required for departure with assistance, but due to the propensity for hydrogen bonding, protonation is more likely to occur at the *syn*-methoxyl moiety to yield the relatively stable hydrogen-bonded intermediate (79). Since hydrogen bonding is weaker for cyclopropane, thereby reducing the selectivity,

anti-methoxyl protonation competes more favorably in the case of saturated ketal (69). Participation of the cyclopropyl ring then becomes a more significant factor as is reflected in the relative rate of 120. The unsaturated *endo*-cyclopropyl ketal (78), if the above mentioned protonation factors were of little consequence, should have hydrolyzed at a rate intermediate to that of ketals (75) and (69), i.e., between the relative rates of 2.3 and 120. The observed relative rate was 320, which Lamaty felt[41] was indicative of the fact that protonation of either methoxyl could result in effective participation from either the double bond or the cyclopropyl group. The rate factor of 18 for ketal (76) was attributed to protonation on the least sterically hindered methoxyl group (*anti*) and the subsequent tilting away of the *syn* methoxyl group from the *exo*-cyclopropyl methylene in the transition state. A relative rate factor of 143 was observed for the *exo*, *endo*-dicyclopropyl ketal (77). Noting that $k_{77}/k_{76} = 8$ while $k_{69}/k_{74} = 120$, Lamaty argued that this was the best example of selective protonation occurring on the least sterically hindered methoxyl coupled with the *syn* hydrogen bonding factor. Kessler has, however, pointed out[43] that according to his product studies, ketal (77) yielded, along with ketone, rearranged product upon acidic hydrolysis. This would affect Lamaty's results since he was following the rate of formation of ketone. Kessler estimated that Lamaty's rate was low by a factor of three.[43a] Later, Kessler repeated[43b] Lamaty's hydrolysis of ketals (69) and (77), but monitered

the product formations via PMR. Using Lamaty's relative value of 120 for ketal (69), Kessler reported a rate ratio of 120:5 for (69) and (77) respectively (120:143, Lamaty). Kessler politely decided not to speculate on the discrepancy between the two research groups. He does speculate that the *exo*-methylene group hinders protonation on the *anti*-methoxyl, and resulting *syn*-methoxyl protonation does not induce participation by the *endo*-cyclopropyl moiety.

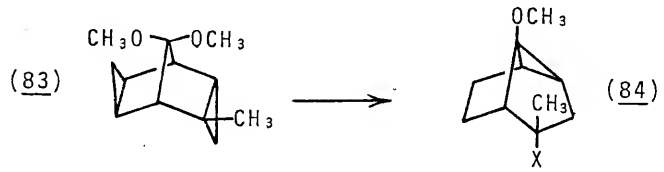
Lamaty has discussed the nature of the ketal hydrolysis intermediate. He found the cyclopentyl ketal (80) to be 5.1×10^3 times more reactive than the 7-norbornyl ketal (74), under the conditions of acid hydrolysis. The 7-norbornanone, however, is 1.7×10^4 more reactive toward nucleophilic addition of borohydride than cyclopentanone.[44] Since he had already reported that the transition state for borohydride addition presents an entirely sp^3 profile,[45] Lamaty felt the reaction profile of the acidic hydrolysis of the 7-norbornyl ketal and the related bridge ketals passes from an initial sp^3 state to a transition state very sp^2 in character, i.e., a carbonium-oxonium ion. There was even speculation that the participation of a double bond or cyclopropyl group would in fact involve interaction with the π^* orbital of the carbonium-oxonium ion.



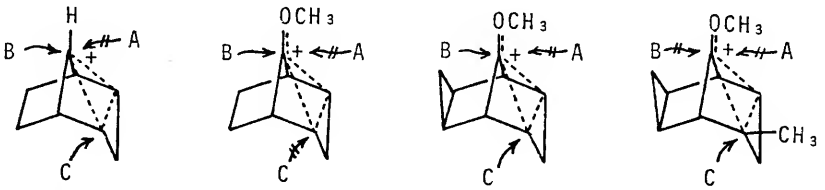
(77) (81) (82)

When Kessler subjected[43] ketal (77) to acidic solvolysis in water or methanol, he found complete conversion to the respective rearranged products, (81)-OH and (81)-OCH_3. Changing the solvent system to dioxane/water or acetone/water produced, in addition of (81)-OH, the ketone (82).

Acidic solvolysis of the methyl derivative (83) led entirely to rearranged products, (81), the methyl group



apparently adding some stabilization of positive charge at C_2.



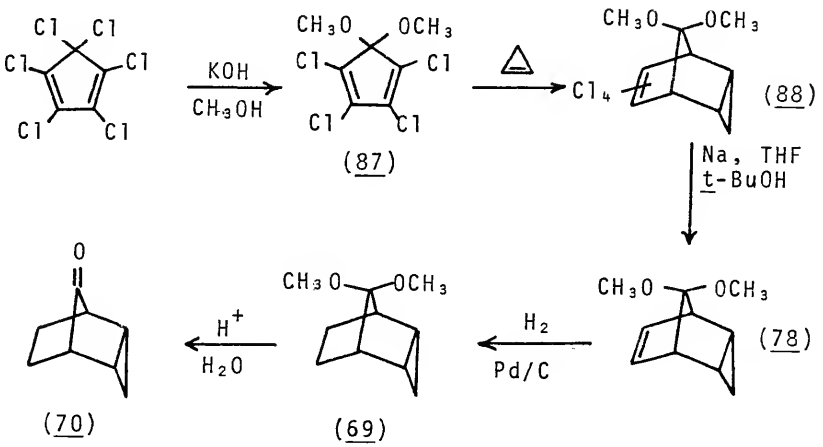
The formed products provide a means for determining the mode of nucleophilic attack on the intermediate carbonium ions, (35), (73), (85), (86), and a summary of these correlations has been made by Kessler.[43] Path A for cation (35) is not observed because of the interaction of the cyclopropyl sigma orbitals with C_8, while B (retention) becomes an extremely minor process in comparison to path C (rearrangement). For cation (73), the methoxyl stabilization of the carbonium ion center allows a "normal" path of hydrolysis to ketone, probably

via path B because of cyclopropyl interaction. In contrast to cation (73), attack by path B for cation (85) is hindered by the methylene group of the *exo* cyclopropyl ring and consequently path C predominates over ketone formation. Kessler did state his belief that path B still dominates over A in the formation of ketone from (85). Cation (86) reacts only with rearrangement due to the stabilizing effect of the methyl group, i.e., via path C.

CHAPTER II

Results and Discussion

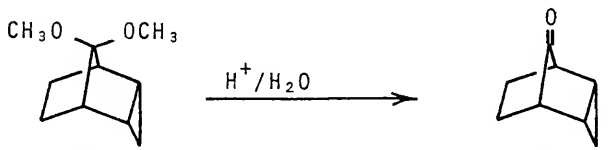
The synthetic scheme employed for the preparation of the precursors and compounds used in this study has been reported by several workers.[21a,22,39]



Hexachlorocyclopentadiene reacted with methanolic[46] potassium hydroxide to give 1,2,3,4-tetrachloro-5,5-dimethoxycyclopenta-1,3-diene, (87). The Diels-Alder addition of cyclopropene to (87) yielded the 1,5,6,7-tetrachloro-8,8-dimethoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene (88).[21a,22,39] Dechlorination of (88) was accomplished via Gassman's procedure[47] giving the 8,8-dimethoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]-oct-6-ene (78).[21a,22,39] Hydrogenation of the unsaturated ketal (78) with palladium/charcoal catalyst produced

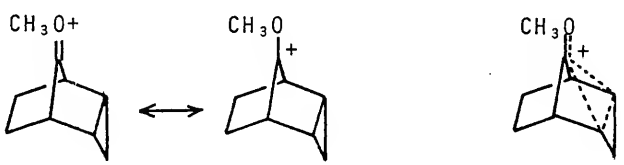
8,8-dimethoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]octane (69).[21a,22,39] Hydrolysis of (69) with wet acetic acid[46c] generated *endo*-tricyclo[3.2.1.$0^{2,4}$]octan-8-one (70). According to an analogous scheme, the diethoxy ketals were also prepared.

The acidic hydrolysis of the *endo*-saturated ketal (69), as described in the introduction, has been reported[21a,22,39] as leading exclusively to *endo*-tricyclo[3.2.1.$0^{2,4}$]oct-8-one (70). Obviously a cationic intermediate is involved, and



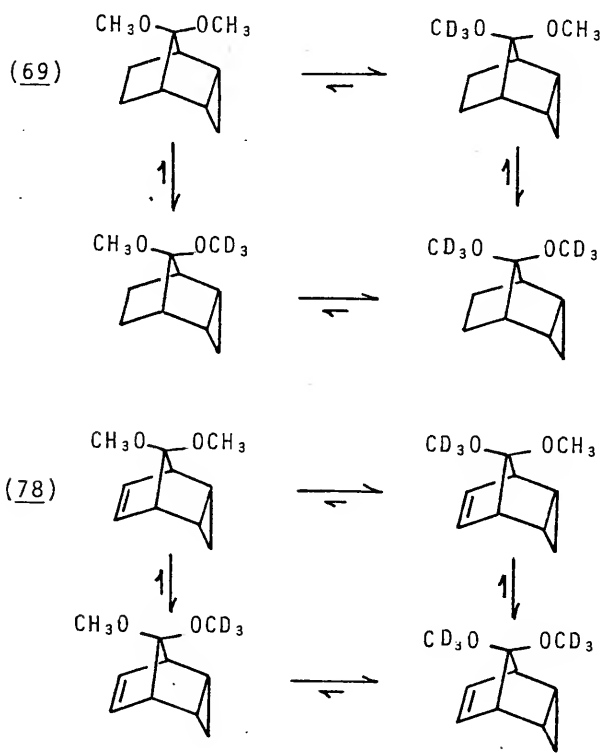
(69) (70)

one is able to speculate upon at least two extremes as to the nature of this cation: 1) essentially a classical, oxo-carbonium ion (72) involving no delocalization of the cyclopropane ring, with the methoxyl stabilized charge at C_8 attacked by nucleophiles only at either face of the bridge or 2) a delocalized non-classical methoxy-tris-homocyclopropenyl cation (73) in which there is both methoxyl and cyclopropyl stabilization resulting in charge concentration at C_8 and nucleophilic attack at the bridge C_8 from the *anti* face stereospecifically.



(72) (73)

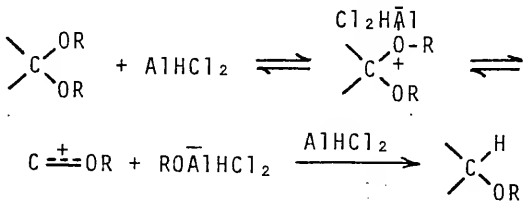
As an initial probe into the nature of the intermediate, both the dimethoxy-saturated and unsaturated ketals, (69) and (78) respectively, were dissolved in d_4-methanol in the presence of catalytic amounts of either silver(I) perchlorate or trifluoroacetic acid. The disappearance of the *syn*- and *anti*-methoxyl signals in the PMR of both ketals was monitored. The *syn* and *anti* designations are assigned with respect to the *endo* cyclopropyl group, and in both ketals, the *syn* methoxyl singlet is assumed to be downfield from the *anti* methoxyl singlet, the verification of which will be reported in Chapter III.



The *anti*-unsaturated methoxyl signal diminished in strength at a rate greater than the *syn*-unsaturated and *anti*-saturated methoxyl signals, which disappeared at ca. the same rate. The *syn*-saturated methoxyl singlet was the most sluggish, but it too was eventually washed out by the d_4-methanol.

While any interpretation of these observations is subject to potential ambiguities, the fact that the *anti*-methoxyl groups for both ketals had a greater propensity for d_4-methanol substitution than their *syn* counterparts would enhance speculation of at least some involvement of the cyclopropyl group with charge development at C_8.

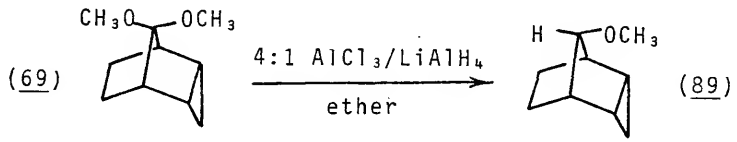
At this point it was considered desirable to generate the intermediate cation by other means, be it (72) or (73), and study the orientation and stereochemistry of nucleophilic capture. Generation of oxo-carbonium ions by the reaction of ketals with dichloroaluminum hydride has been documented in the literature[48] The dichloroaluminum hydride, which exists in ether as an etherate, complexes with an oxygen of the ketal, which in turn fragments to give an oxo-carbonium ion. Subsequent attack by hydride or other nucleophiles gives



an ether product.[48c,d] Eliel suggested[48a] using a 4:1 molar ratio of aluminum chloride to lithium aluminum hydride as

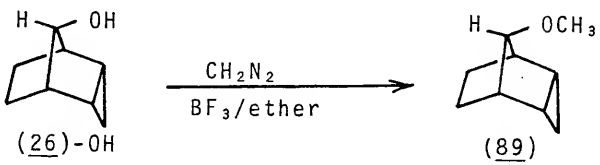
the most efficient means of generating dichloroaluminum hydride, and the ratio is employed in this work.

The reaction of 8,8-dimethoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]-octane (69) with a 4:1 molar ratio of aluminum chloride/lithium aluminum hydride for 1.75 hours produced *syn*-8-methoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]octane (89) in 82.8% yield. The colorless



(69) (89)

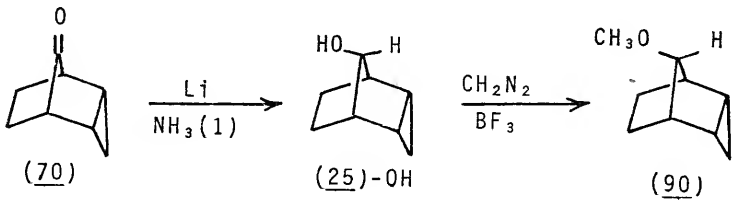
liquid was identified by its PMR spectrum δ[3.82(1,m), 3.34 (3,s), 2.18 (2,m), and 1.67 to 0.67 (8, complex)], mass spectrum (m/e 138), infra-red spectrum, and elemental analysis. An alternative synthesis for (89) was accomplished by the reaction of diazomethane with an authentic sample[49] of *endo-syn*-tricyclo[3.2.1.$0^{2,4}$]octan-8-ol, (26)-OH, confirming the assigned structure of (89) via spectral comparison.



(26)-OH (89)

Glpc/mass spectral analysis of the crude dichloroaluminum hydride product mixture resulted is the detection of four minor reaction proucts totaling 5.3% relative to the major product (89). The highest recorded m/e values were 136, 128 and 179 respectively for the third, fourth, and fifth eluted components.

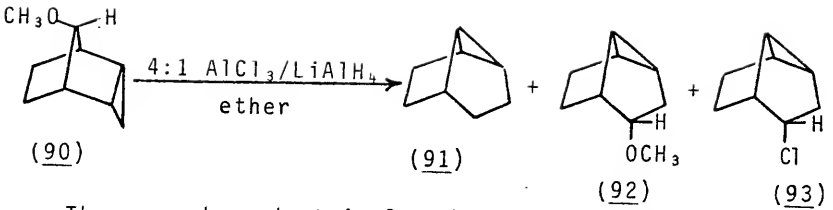
The fact that none of these trace products were attributable to the intermediate formation of any *anti*-8-methoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]octane (90) was demonstrated by the synthesis of (90) and its subsequent exposure to the reaction conditions. Reduction of ketone (70) with lithium metal in



(70) (25)-OH (90)

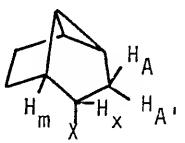
liquid ammonia[39] gave product which consisted of 94.5% *anti*-alcohol (25)-OH. Treatment of (25)-OH with distilled diazomethane etherate and boron trifluoride catalyst produced *anti*-8-methoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]octane (90) which was characterized by its PMR spectrum δ[3.62 (1,m), 3.23 (3,s), 2.21 (2,m), and 1.80 to 0.28 (8, complex)], absolute mass measurement of $[C_9H_{14}O]^+$, infra-red spectrum, and elemental analysis.

anti-Ether (90) was stirred for 1.75 hours with 4:1 aluminum chloride/lithium aluminum hydride reagent and three products were isolated via preparative glpc. Tricyclo-[3.3.0.$0^{2,8}$]octane (91) was collected as a colorless liquid in 28.6% yield. The PMR and infra-red spectra were in accord with an earlier report,[46c] and the absolute mass measurement of $[C_8H_{12}]^+$ along with the elemental analysis confirmed the structure.



(90) (91) (92) (93)

The second product isolated was *endo*-4-methoxytricyclo-[3.3.0.$0^{2,8}$]octane (92) in 33.7% yield. The PMR spectrum δ[3.75 (1,ddd), 3.19 (3,s), and 2.70 to 0.87 (10, complex),], mass spectrum (138 m/e) and absolute mass measurement of $[C_9H_{14}O]^+$, infra-red spectrum, and elemental analysis all confirmed the assigned structure. The *endo* configuration



(92) and (93):

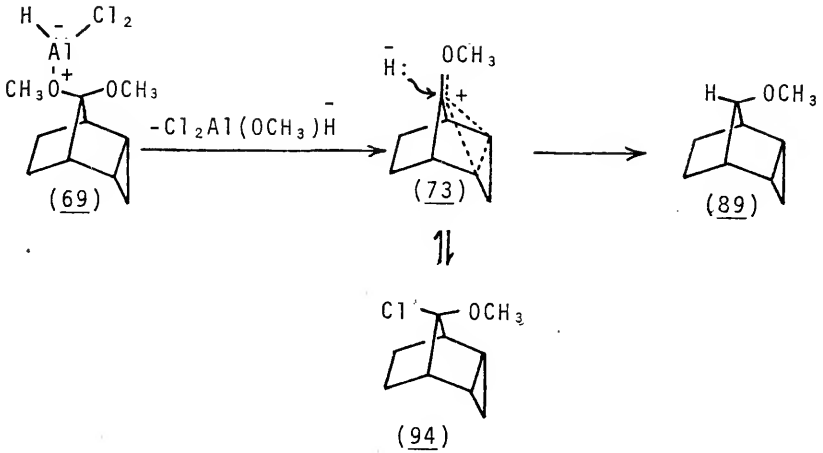
$J_{AX}=J_{A'X}$ = 9.0 Hz; J_{mx}=6.0 Hz

was verified by analysis of PMR couplings for H_X which agree with reported data[21c,22,36,37,43b] for *endo* analogs.

The third product (7.7%) was identified as *endo*-4-chlorotricyclo[3.3.0.$0^{2,8}$]octane (93) from its PMR spectrum δ[4.18 (1,ddd), and 2.86 to 103 (10, complex)], mass spectrum (142 m/e), and the absolute measured mass for $[C_8H_{18}Cl]^+$. The *endo* configuration was also verified by the coupling pattern for H_X.

The detection of only *syn*-ether (89) from saturated ketal (69) and dichloroaluminum hydride with no evidence for the formaton of the epimeric *anti*-ether (90) adds considerable weight to the existence of the non-classical intermediate

(73). Following coordination of dichloroaluminum hydride

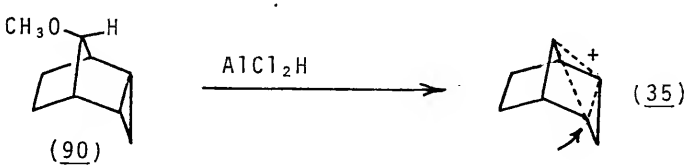


(69) (73) (89) (94)

with the *anti*-methoxyl group of (69), it could be anticipated that this *anti* complex would depart with assistance from the cyclopropyl group. The observation that the *anti*-ether (90) is labile under the reaction conditions while the *syn*-ether (89) is stable lends credence to this hypothesis. There is, however, no compelling evidence to suggest which methoxyl group in 69 is intially lost. In any event ionization to the intermediate cation (represented as non-classical (73) for the sake of argument) and subsequent attack by one or each of three formal nucleophiles, i.e., methoxide, chloride, and hydride, would explain the observed product(s). Attack at C_8 is apparently favored by a concentration of positive charge at this site in either the classical (72) or non-classical (73) models. Methoxide attack would regenerate starting ketal (69), while chloride attack would afford the highly reactive α-chloro-ether (94) which should quickly regenerate the cationic

intermediate under the reaction conditions. Hydride attack at C_8 accounts for the observed product, *syn*-ether (89), whose formation exclusive of C_2 attack and any *anti*-ether (90) demonstrates stereospecific hydride capture from the *anti* face of C_8. This is of course, indicative of interaction and delocalization of charge at C_8 with the cyclopropyl ring and the methoxyl group, but with the methoxyl stabilization concentrating the charge at C_8 to a point at which the steric bias for the transition state of *endo* rearranged product formation is overcome.

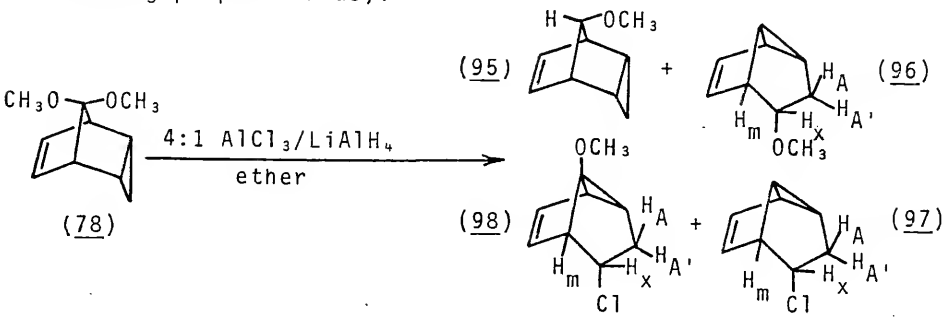
The formation of only *endo*-rearranged products from the reaction of dichloroaluminum hydride with *anti* -ether (90) is in line with earlier results for nucleophillic capture of the solvolytically generated parent tris-homocyclopropenyl cation (35). In the case of (90), all three potential nucleophiles are observed in the product analysis, a relatively rare result[4,8e] for dichloroaluminum hydride reactions.



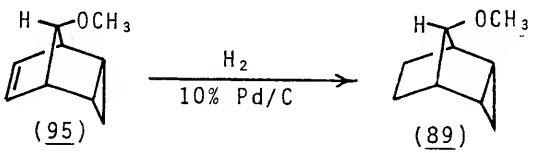
(90) (35)

At this point it became desirable to investigate the reaction of dichloroaluminum hydride with 8,8-dimethoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene (78), particularly with respect to any potential anchimeric competition between the cyclopropyl group and the carbon-carbon double bond. Reaction of unsaturated ketal (78) with a 4:1 molar ratio of aluminum

chloride/lithium aluminum hydride gave four products which were isolated via preparative glpc (yields reported are relative glpc peak areas).



The major product (76.5%) isolated was *syn*-8-methoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene (95) which was identified from its PMR spectrum δ[0.53-0.94 (2, complex), 1.26-1.57 (2, complex), 2.66-2.88 (2,m), 3.25 (3,s), 3.50 (1,m) and 5.61 (2,t)], the mass spectrum (136 m/e), infra-red spectrum, and elemental analysis. Hydrogenation of (95) with 10% Pd/charcoal catalyst produced the previously characterized



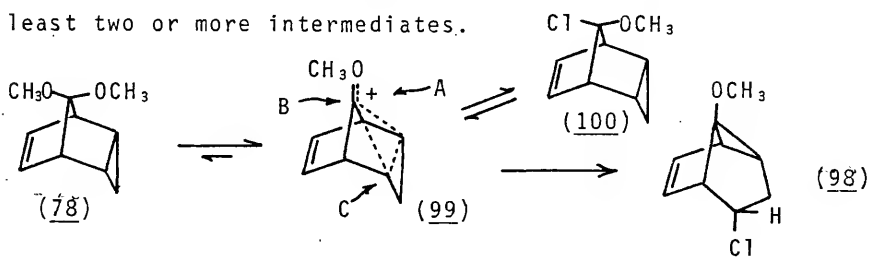
saturated *syn*-ether (89) to further verify the structure.

endo-6-Methoxytricyclo[3.3.0.$0^{2,8}$]oct-3-ene (96) was isolated in 3.5% relative yield and was characterized by its PMR δ[5.65 (2,m), 3.95 (1,ddd), 3.24 (3,s), 2.79 (1,m), and 2.48 to 0.58 (5, complex)] and mass (136 m/e) spectra. The *endo* configuration was verified by the PMR couplings[21c,22,36,37,43b] for H_X: J_{AX}=9.25; $J_{A'X}$=7.75; and J_{MX}=5.0.

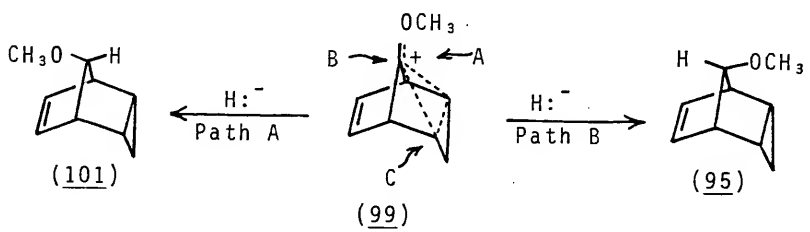
endo-6-Chlorotricyclo [3.3.0.$0^{2,8}$]oct-3-ene (97), collected in 1.0% yield, received the assigned structure on the basis of the literature authenticated[50] PMR spectrum δ[5.70 (2,m), 4.28 (1, oct), 3.24 (1,m), 2.57 to 1.34 (5, complex)], mass spectrum (140 m/e), and spectral comparison with a sample derived for an alternative synthetic route to be reported later in the text. The *endo* configuration was confirmed[21c,22,36,37,43b] by the PMR couplings of H_X: J_{AX} = 10.0; $J_{A'X}$ = 8.0; and J_{MX} = 5.0 Hz.

The last component was identified as 1-methoxy-*endo*-6-chlorotricyclo[3.3.0.$0^{2,8}$]oct-3-ene (98) and was collected in 18.9% yield. The elemental analysis, infra-red spectrum, mass spectrum (170 m/e), and PMR spectrum δ[5.73 (2,t), 4.37 (1,m), 3.39 (1,m), 3.29 (3,s), and 2.60 to 1.27 (4, complex)] agreed with the structural assignemnt. The PMR coupling for H_X confirmed[21a,22,36,37,43b] the *endo* configuration: J_{AX} = 10.0; $J_{A'X}$ = 7.75; and J_{MX} = 5.25 Hz. Further structural proof is given later.

At first glance, the product bulk appears explanable on the basis of the intermediacy of the 8-methoxy-tris-homocyclopropenyl cation (99), however the detection of the minor products (96) and (97) requires the invocation of at least two or more intermediates.



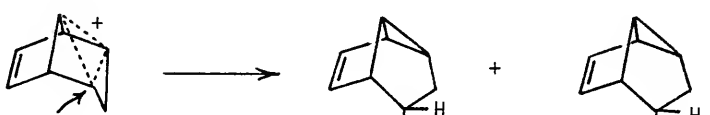
The formation of unsaturated rearranged chloride (98) would appear to be the result of chloride attack upon the non-classical cationic intermediate (99), which would be generated by the complexation of dichloroaluminum hydride with the *anti*-methoxyl group of ketal (78) with subsequent departure of the *anti* complex via the anchimeric assistance of the cyclopropyl group. The chloride anion would then have path B (C_8, anti-face) or path C (C_2, *endo*) as possible routes to cation collapse. Path C, of course, would lead directly to product (98) but it would be anticipated that C_8 attack (path B) would predominate in line with the observed course of reduction (hydride attack). If formed, the resulting unstable bridge α-chloro-ether (100) could then suffer rearrangement to the thermodynamically more stable, rearranged chloride (98) via a tight ion pair intermediate.[21b,22] If the intermediate cation was essentially classical, i.e. (71), one would expect a mixture of both the *syn* (path A) and *anti* (path B) α-chloro-ether at C_8, both of which should be very reactive. As already mentioned, generation of a classical cation via *syn* ionization followed by leakage into the non-classical manifold has been domonstrated to occur when cationic stabilizing groups are located on C_8.[37,38]



(101) (99) (95)

Hydride attack upon (99) at the C_8 position accounts for the major product, *syn*-unsaturated ether (95). The non-classical description of (99) would require the stereospecific approach from the *anti* face (path B). Approach from the *syn* face (path A) by hydride would generate the *anti*-8-methoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene, (101), whose transient existance, as will be seen, is highly probable. There are, however, potential alternative routes to the formation of (101) which will shortly be discussed. Hydride attack via path C was not observed which is entirely consistent with hydrolytic results for ketal (78), and makes the observations of rearranged chloride (98) all the more interesting.

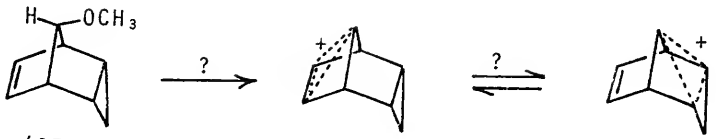
Methoxide quenching of cation (99) at C_8 would regenerate (path B likely) the starting material, unsaturated dimethyl ketal (78). Under the experimental conditions, this process would not be detected.



(102) (96) (97)

The characterization of the two non-methoxylated *endo* rearranged minor products (96) and (97) argues strongly for the intermediacy of the unsubstituted 2,4-etheno-tris-homocyclopropenyl cation (102) which would suffer nucleophilic attack via path C to give the observed products (96)

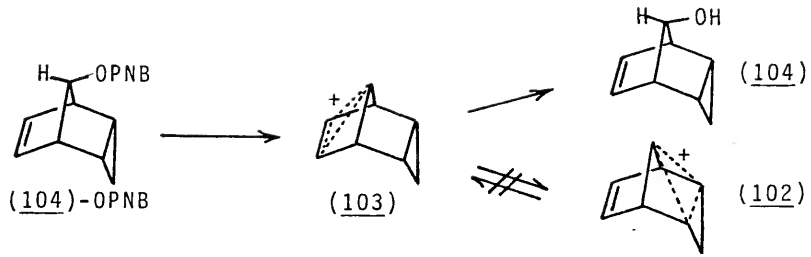
and (97). There appear to be a number of viable mechanistic routes to (102).



(95) (103) (102)

One mechanistic pathway questions the stability of the major product, *syn*-unsaturated ether (95), under the reaction conditions. Coordination of dichloroaluminum hydride as a Lewis acid with the *syn*-methoxyl group of (95) could result in cleavage of the ether with anchimeric assistance by the internal carbon-carbon double bond generating the unsubstituted bis-homocyclopropenyl cation, (103). The previously mentioned theoretical calculations of Hoffmann[15] predict a lower ground state energy for the tris-homocyclopropenyl cation (102) relative to the bis-homocyclopropenyl cation (103), suggesting the possibility of interconversion or equilibration, favoring (102), between the two ions, with subsequent nucleophile capture by cation (102) to give the observed products.

It has been reported,[51] however, that the hydrolysis of the *p*-nitrobenzoate ester of the *syn* unsaturated alcohol, (104)-OPNB, yields only the retained *syn*-alcohol (104), presumably via the bis-homocyclopropenyl intermediate (103). Apparently (103) and (102) do not interconvert under the reactions conditions because bridge flipping is not competitive with solvent capture.[51]



The *syn* unsaturated ether (95) itself was subjected to the original reaction conditions and was exposed to the dichloroaluminum hydride reagent for a three hour period. Capillary glpc analysis revealed that 93% of the *syn* ether (95) had not reacted, with the detection of only 6% of an unknown hydrocarbon and 1% of an unknown whose retention time was too great to be either (96) or (97). As a consequence of the above facts, the generation of the tris-homocyclopropenyl cation (102) from *syn*-ether (95) via the bis-homocyclopropenyl cation (103) is effectively eliminated as a mechanistic pathway.

One alternative approach to the formation of cation (102) could involve the intermediacy of 8-methoxy-bis-homocyclopropenyl cation (105). The generation of cation (105) might be accomplished by equilibration between (105) and the 8-methoxy-tris-homocyclopropenyl cation (99), since the energy barrier to bridge flipping should be lowered[52] relative to cations (102) and (103) as a result of the methoxyl stabilization of positive charge at C_8 in (99). Of at least equal probability is the dichloroaluminum hydride promoted cleavage of the *syn*-methoxyl group in unsaturated ketal (78), with concomitant

anchimerical assistance by the double bond to give cation (105) directly.

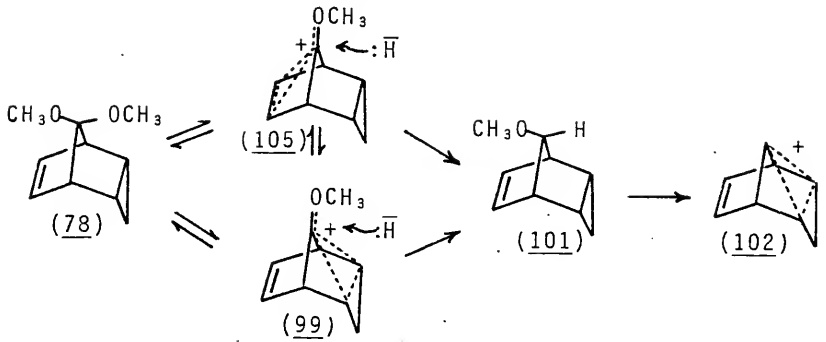
The viability of the bridged ion (105) as an intermediate is somewhat speculative considering reports[53] that substitution of a *p*-anisyl group at the bridge (C_7) carbon of norbornene cancels out (levels) stabilization provided by the double bond upon the cation generated at the bridge. Direct spectral observation[52] of the 7-methoxynorbornenyl and norbornadienyl cation, however, has provided some evidence that delocalization involving one or both double bonds, respectively, exists for these ions.

An 8-methoxy-bis-homocyclopropenyl cation (105) would be expected to suffer hydride attack from the *anti* face (with respect to the double bond) at C_8 to generate the *anti*-8-methoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene (101).

Ether (101) could also have been generated by hydride attack on the tris-homo cation (99) from the *syn* face of C_8, allowing for weakened interaction of the cyclopropyl group and incorporation of considerable classical character. By analogy, it has been shown that from strictly steric point of view, *anti* attack is already favored over *syn* attack without any potential complications of delocalization. Borohydride reduction[39] of the unsaturated ketone (106) produced a 3:1 predominance of *syn*-alcohol (104) over *anti*-alcohol (107).

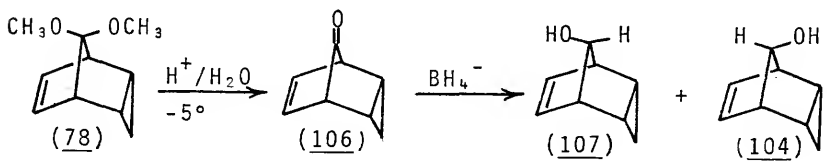
Whatever the origin of (101), coordination of its anticipatorily labile *anti*-methoxyl group with dichloroaluminum hydride, followed by the cyclopropyl assisted ionization of the complex, would generate the unsubstituted non-classical

cation (102), with subsequent product formation.



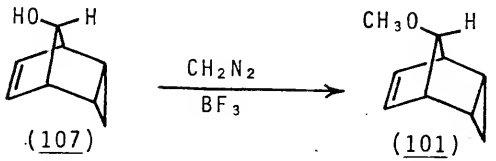
In order to test the later part of this hypothesis, it was deemed advantageous to synthesize the unsaturated *anti*-ether (101), subject this ether to the original reaction conditions, and analize the resultant product mixture for the presence of (96) and (97).

The synthesis of *endo, anti*-tricyclo[3.2.1.$0^{2,4}$]oct-6-en-8-ol, (107) was accomplished via the method of Clark, Frayne, and Johnson.[39] The unsaturated ketal (78) was sub-



jected to acidic hydrolysis at -5° to yield a concentrated solution of the thermally unstable (decarbonylation) *endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-en-8-one (106). Ketone (106) was never isolated but was reduced in solution by sodium borohydride to yield ca. 75:25 mixture of the *syn*-alcohol (104) and *anti*-alcohol (107). Isolation via preparative glpc of *anti*-alcohol (107), whose spectral data were in agreement

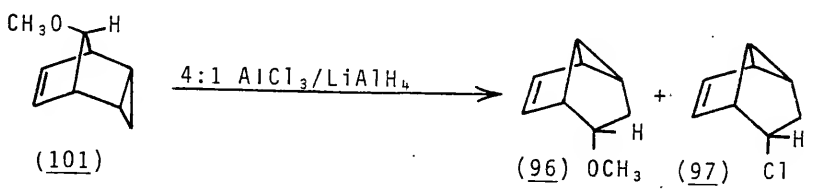
with the literature,[39] was followed by methylation by diazomethane with boron trifluoride catalyst to yield the desired



(107) (101)

anti-8-methoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene (101). Structural identification of (101) was established by its PMR spectrum δ[5.67 (2,m), 3.62 (1,m), 3.21 (3,s), 2.93 (2,m), 1.14 (2,m), .33 (2,m)], mass spectrum, and the measured mass for $[C_9H_{12}O]^+$.

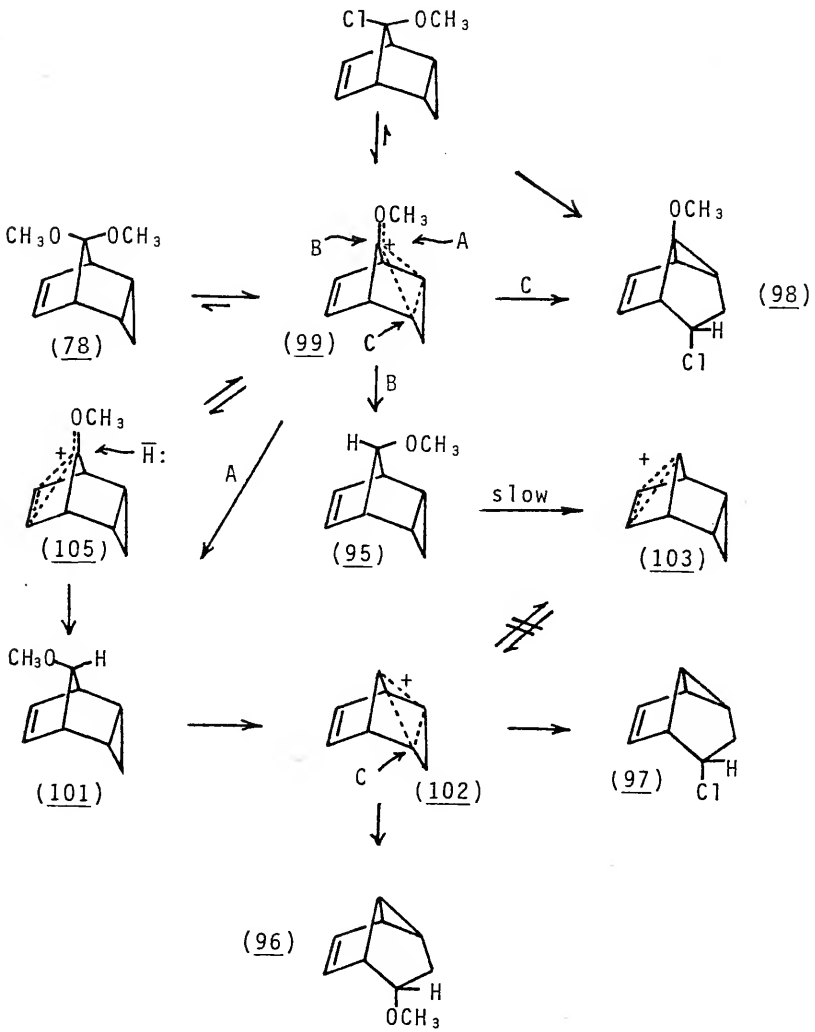
Exposure of the *anti*-unsaturated ether (101) to the original reaction conditions was followed by capillary glpc analysis of the resultant product mixture. Both the *endo*-rearranged methoxy- and chloro-octenes, (96) and (97), were established via authentic compound comparison to be present



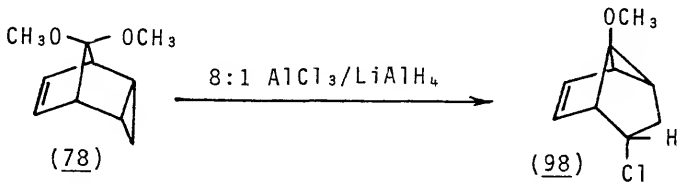
(101) (96) OCH_3 (97) Cl

in a relative ratio of ca. 3.2.:1 compared to the original ratio of ca. 3.5:1 obtained from the ketal reduction. The two products accounted for the bulk (61.1%) of the reaction mixture with no unreacted ether (101) detected. The results above strongly endorse the viability of *anti*-unsaturated ether (101) as an initial reduction product in the reaction of dichloro-

aluminum hydride reagent with the unsaturated dimethyl ketal (78). A summary mechanistic scheme for the reduction of unsaturated ketal (78) is presented below.

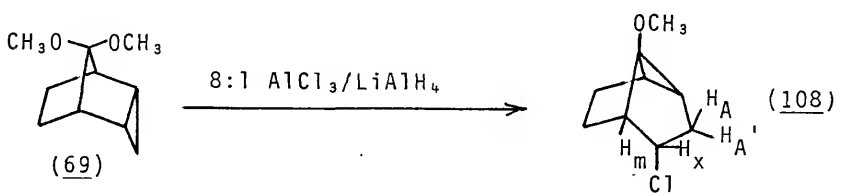


If the mechanistic rational presented for the formation of the *endo*-unsaturated rearranged chloro-ether (98) is correct, one should expect that an increase in the molar ratio of aluminum chloride/lithium aluminum hydride should lead to increased yields of chloro-ether product, since the availability of the chloride anion is increased while the hydride molar equivalents are decreased. An 8:1 molar ratio was employed in reactions with both the saturated and unsaturated ketals (69) and (78). The small amount of hydride present effectively serves to destroy any moisture or proton acid build-up.



(78) (98)

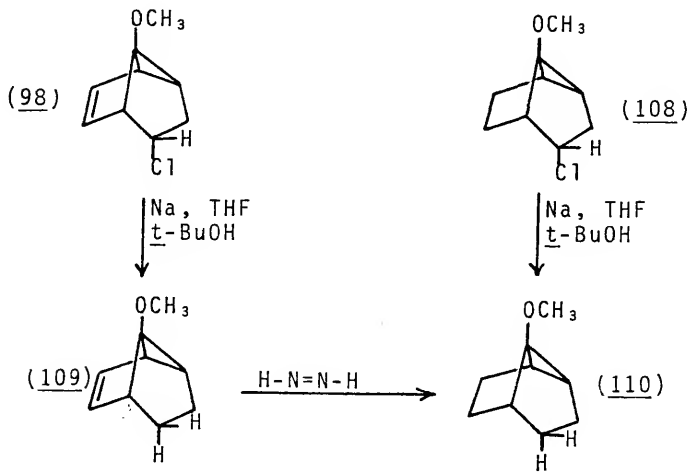
Use of the 8:1 reagent with the unsaturated ketal (78) gave a 71.8% yield of 1-methoxy-*endo*-6-chlorotricyclo[3.3.0.$0^{2,8}$]-oct-3-ene (98) as a dark yellow oil which, despite the color, was glpc pure. The color was removed upon vacuum distillation.



(69) (108)

Treatment of the saturated ketal (69) with the 8:1 $AlCl_3/LiAlH_4$ reagent gave an 81.1% yield of 88.5% glpc pure 1-methoxy *endo*-tricyclo[3.3.0.$0^{2,8}$]octane (108). Three minor components

(7.7. 1.7, and 2.1%) of slightly shorter retention time were not identified. The structure of the methoxy saturated chloride (108) was verified by its PMR spectrum δ[4.40 (1,ddd), 3.35 (3,s), and 3.02 to 1.13 (9, complex)], mass spectrum (172 m/e), measured mass for $[C_9H_{13}OCl]^{+\cdot}$, and infra-red spectrum. The *endo* configuration was confirmed by the coupling pattern[21c,22,36,37,43b] for Hx: J_{AX} = 9.75; $J_{A'X}$ = 8.75; and J_{MX} = 6.5.



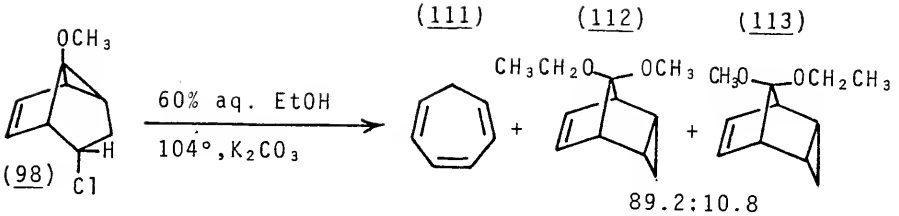
As a further verification of the structure of the unsaturated and unsaturated chlorides (108) and (98), both compounds were dechlorinated using Gassman's procedure.[47] Treatment of unsaturated chloride (98) with sodium metal in tetrahydrofuran/*tert*-butanol gave a 44.2% yield of a pale yellow oil which was identified as 1-methoxytricyclo[3.3.0.$0^{2,8}$]oct-3-ene (109). Identification was accomplished from the PMR spectrum δ[5.53 (2,m), 3.33 (3,s), 3.13 (1,m), and 2.40 to 1.22 (6, complex)],

mass spectrum (136 m/e), measured mass for $[C_9H_{12}O]^+$, infra-red spectrum, and elemental analysis.

In a similar manner, the sodium metal dechlorination of saturated chloride (108) produced a 49.6% yield of a colorless liquid identified as 1-methoxytricyclo[3.3.0.$0^{2,8}$]octane (110). The structural assignment was based on the PMR spectrum δ[3.37 (3,s), 2.74 (1,m), and 2.30 to 1.08 (10, complex)] mass spectrum (138 m/e), infra-red spectrum, and elemental analysis.

The skeletal relationship between the saturated and unsaturated dechlorinated tricycles (110) and (109) was demonstrated by the diimide reduction of the olefinic bond of (109) to yield the saturated compound (110) as confirmed by spectral comparison. The use of the relatively mild diimide reduction procedure was necessitated by the fact that hydrogenation of (109) over 10% Pd/C absorbed ca. twice the theoretical amount of hydrogen, leading one to assume that the methoxylated cyclopropyl ring was also being reduced.

Since the saturated and unsaturated rearranged chlorides (108) and (98) had become readily available from the synthetic point of view, and since their ionization should also lead directly into their respective tris-homocyclopropenyl cation manifolds, these systems provide excellent precursors to the identical intermediates involved both in the acidic hydrolyses of the saturated and unsaturated ketals (69) and (78), and the reaction of these ketals with dichloroaluminum hydride. This includes, of course, a rather confident assumption of a delocalized structure for these intermediates.



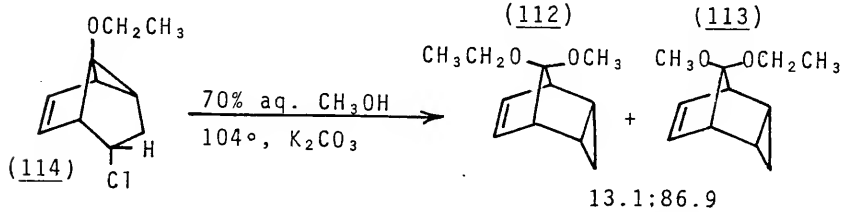
The first examined was the unsaturated rearranged methoxy chloride (98) which was solvolyzed in 60% aqueous ethanol in the presence of potassium carbonate at 104° for ten hours. Capillary glpc analysis displayed only two components whose respective yields were determined by internal standards. Both fractions were isolated via preparative glpc. The first eluted component (53.6%) was determined to be cycloheptatriene (111) by spectral comparison with an authentic sample.

The second fraction consisted of mixed alkoxy ketals (21.5%) and was determined by PMR to be made up primarily (89.2%) of *anti*-8-ethoxy-*syn*-8-methoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]-oct-6-ene (112). The PMR spectrum δ[5.72 (2,t), 3.38 (2,q), 3.27 (3,s), 2.86 (2,m), ca. 1.24 (2,m), 1.13 (3,t), and .47 (2,m)], mass spectrum (180 m/e), and absolute mass measurement for $[C_{11}H_{16}O_2]^+\cdot$ all agreed with the designated structure. The assignment of *syn* for the methoxyl group and *anti* for the ethoxy group is based on the fact that the cyclopropyl group's field effect causes a greater downfield shift than the double bond, a trend that will be summerized later with regard to all the ketals and methyl ethers encountered in this text. A singlet appearing at δ3.13 in the PMR of the mixed ketal fraction was tentatively attributed the *anti*-methoxyl hydrogens

of *anti*-8-methoxy-*syn*-8-ethoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene (113), and, through PMR integration, was determined to be 10.8% of the mixed ketal product. It is most noteworthy that the *syn* and *anti* methoxyl signals of both mixed ketals are identical to the chemical shift values of the respective *syn* and *anti* methoxyl signals for the dimethoxy unsaturated ketal (78).

The need to firm up the PMR assignments for the two mixed ketals (112) and (113) was immediately recognized, the complete characterization of ketal (113) being of prime importance.

The ethoxy analog of the methoxy rearranged unsaturated chloride (89), i.e., 1-ethoxy-*endo*-6-chlorotricyclo[3.3.0.$0^{2,8}$]-oct-3-ene (114) was synthesized by the identical procedure for (98), and subsequently subjected to solvolysis in 70% aqueous methanol at 104° for 24 hours.

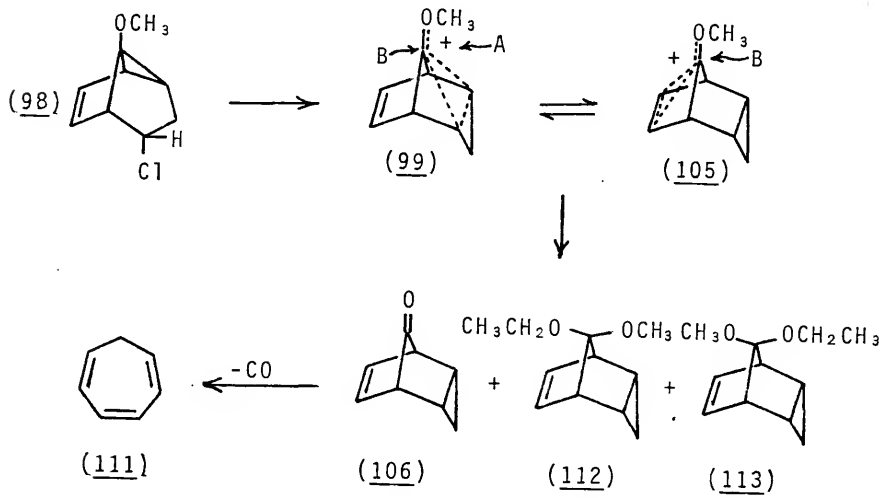


(114) 13.1:86.9

The mixed ketal fraction isolated was found by PMR to consist for the most part (86.9%) of *anti*-methoxy-*syn*-ethoxy unsaturated ketal (113). In addition to the PMR spectrum δ[5.70 (2,t), 3.53 (3,q), 3.13 (3,5), 2.87 (2,m), ca. 1.26 (2,m), 1.22 (3,t) (3,g), and 0.48 (2,m)], the mass spectrum (180 m/e), and the absolute measured mass for

$[C_{11}H_{16}O_2]^+$ were in agreement with the structural assignment. A singlet at δ3.27 was attributed to the *syn* methoxyl PMR absorption of *anti*-ethoxy-*syn*-methoxy unsaturated ketal (112), and (112) was calculated through integration to comprise 13.1% of the mixed ketal fraction.

The solvolysis products are uniquely explained by cyclopropyl anchimeric assistance in the ionization of the rearranged unsaturated chloride (98) to the non-classical tris-homocyclopropenyl cation (99). If cation (99) should then be



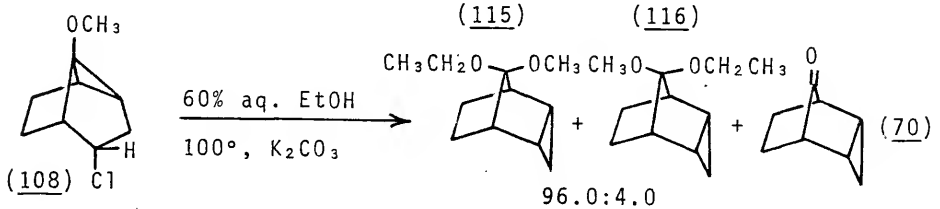
rapidly interconverted with the bis-homocyclopropenyl cation (105), the major ketal product, *anti*-ethoxy-*syn*-methoxy unsaturated ketal (112), would be a result of ethanol attack from the *anti* face of C_8 in (99), (path B), and formation of the minor ketal product, *anti*-methoxy-*syn*-ethoxy unsaturated ketal (113) could be attributed to ethanol approach at C_8 of bis-homo cation (105) via path B, i.e., from the *anti* face

with respect to the delocalized double bond. Of at least equal probability would be attack of cation (99) by ethanol along path A to give (113), assuming a weakly delocalized system or a symmetrically bridged intermediate ion. Leakage of (99) to a classical oxocarbonium ion, followed by solvent attack from both *syn* and *anti* faces, cannot be ruled out, but appears to be less consistent with all the results.

Attack by water at C_8 of the intermediate(s) ion would generate the major product, unsaturated ketone (106). Under the experimental conditions, ketone (106) is known[21b,39,54] to decarbonylate giving cycloheptatriene (111).

It is quite significant to note that, despite the indication that cation (99) was generated from the rearranged precursor (98), no rearranged products (path C) were observed. This point can only add emphasis to the concentration of positive charge at C_8 in the delocalized cation (99).

The behavior of the saturated rearranged chloride (108) under solvolytic conditions was subsequently studied. Chloride (108) was heated for 19 hours at 100° in 60% aqueous ethanol

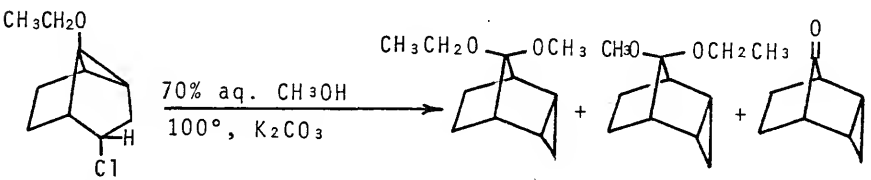


in the presence of potassium carbonate. Capillary glpc analysis with an internal standard revealed two fractions. The largest fraction was determined to be *endo*-tricyclo-

[3.2.1.$0^{2,4}$]octan-8-one (70), in a calculated yield of 68.1%. Ketone (70) was identified by spectral and glpc comparison with a known sample.

The ketal fraction (19.2%) was determined by PMR to consist mostly (96.0%) of *anti*-8-ethoxy-*syn*-8-methoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]octane (115). The PMR spectrum δ3.47 (2,q), 3.33 (3,s), 2.13 (2,m), 1.78 to 0.52 (8, complex), 1.18 (3,t), mass spectrum (182 m/e), and absolute measured mass for $[C_{11}H_{18}O_2]^+$ all supported the designated structure. The *anti*-methoxyl group of *anti*-8-methoxy-*syn*-8-ethoxy-*endo*-tricyclo-[3.2.1.$0^{2,4}$]octane (116) was tentatively assigned to a PMR singlet appearing at δ3.22, and comparative integration of the methoxyl signals of (115) and (116) revealed the minor component (116) to be 4.0% of the total ketal fraction.

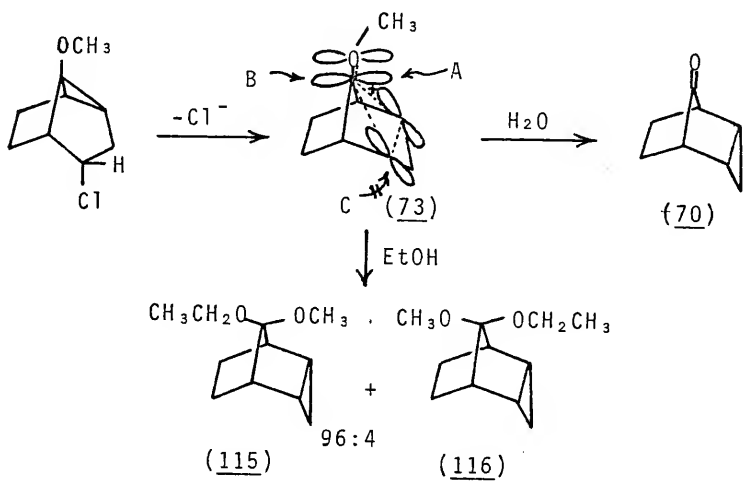
As was the case with the unsaturated mixed ketals, there was a demonstrated need for the complete characterization of *anti*-methoxy-*syn*-ethoxy ketal (116) to add assurance to the above assignments. The ethoxy analog of the methoxy rearranged saturated chloride (108), namely, 1-ethoxy-*endo*-4-chloro-tricyclo[3.3.0.$0^{2,8}$]octane (117), was synthesized via the identical method for (108), followed by solvolysis in 70% aqueous methanol for 27 hours at 100°.



(117) (115) (116) (70)

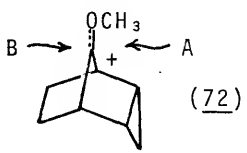
The product analysis of the two fractions isolated revealed the largest fraction (71.3%) to be tricyclic ketone (70). The great bulk (96.3%) of the ketal fraction was determined to be *anti*-8-methoxy-*syn*-8-ethoxy-*endo*-tricyclo-[3.2.1.$0^{2,4}$]octane (116) as demonstrated by the PMR spectrum δ[3.59 (2,q), 3.22 (3,s), 2.12 (2,m), 1.84 to .51 (8, complex), and 1.24 (3,t)], mass spectrum (182 m/e), and absolute measured mass for $[C_{11}H_{18}O_2]^+$. A singlet at δ3.33 was assigned to the *syn*-methoxyl PMR signal of *anti*-ethoxy-*syn*-methoxy saturated ketal (115), which was determined via integration to be 3.7% of the ketal fraction.

The anchimerically assisted ionization of saturated rearranged chloride (108) is supported by the fact that only C_8 nucleophilic attack (paths A or B) on cation (73) was observed from the product analysis. Going from the rearranged



structure of (108) to the unrearranged products to the exclusion of path C adds to the concept of positive charge concentration at C_8, and the highly stereoselective attack (96%) of solvent on cation (73) from the *anti* face (path B) of C_8 underlines the delocalized nature of the intermediate. The detection of 4% *anti*-methoxy-*syn*-ethoxy saturated ketal (116) leads to the rather obvious question of *syn* attack (path A) on what is conceived of as being a delocalized cation (73). It could be anticipated that since the methoxyl group competes so favorably with the cyclopropyl ring with regard to charge stabilization, any potential rehybridization of C_8 from sp^2 to sp^3 would effectively be eliminated, resulting in a protruding, electron-deficient "p" orbital, occasionally accomplishing nucleophilic capture from the *syn* face of the bridge, despite residual cyclopropyl delocalization.

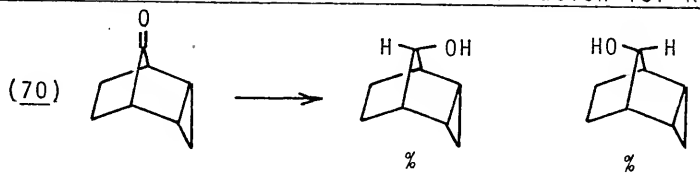
At the same time, the product distribution hardly argues for the intermediacy of the classical cation (72) since there is simply no explanation at this point for the overwhelming attack of nucleophiles via path B for (72). As



(72)

can be seen from Table I, the reduction of tricyclic ketone (70) with numerous reagents shows no overwhelming steric preference for hydride attack via paths A or B, and certainly not to the point of 96% *anti*-attack.

Table I. Hydride Reduction Product Distribution for Ketone (70)



	%	%
$LiAlH_4$[55]	67	33
$NaBH_4$[46c]	58	42
LiAl(Ot-Bu)H[46c]	58	42
Al(i-PrO) /i-PrOH[46c]	20	80
Li(secBu)$_3$BH[a]	90.5	9.5
PMHS/DBATO[a,b]	63	37

[a]This work

[b]Polymethylhydrogen siloxane/tetrabutyldiacetoxytin oxide dimer

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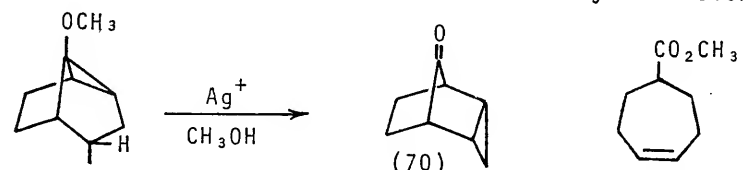
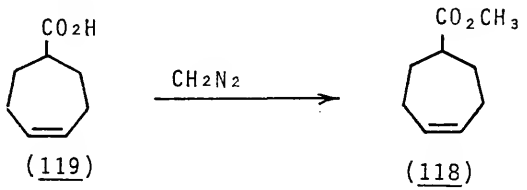
Yet another means of generating the non-classical methoxy *tris*-homocyclopenyl cation (73) was found in the reaction of saturated rearranged chloride (108) with silver perchlorate in methanol/acetone. The tricyclic ketone (70)



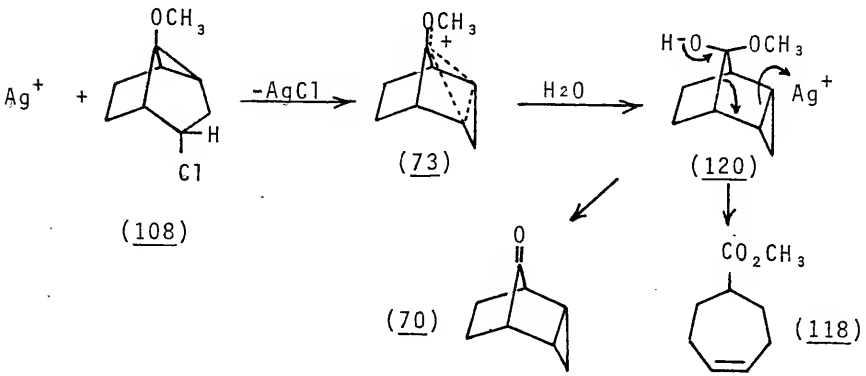
(108) Cl (70) (118)

was isolated (30.7%) and identified via spectral comparison with an authentic sample. The second component (34.7%) was identified as methyl 4-cycloheptene-1-carboxylate (118) from its PMR spectrum δ[5.75 (2,t), 366 (3,s), and 2.82 to 1.21

(9, complex)], mass spectrum (154 m/e), and infra-red spectrum, all of which agreed with the published spectral data.[56] Ester (118) was also synthesized from 4-cycloheptene-1-carboxylic acid (119) and diazomethane, followed by spectral comparison and authentication.



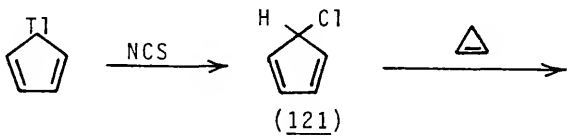
(119) (118)



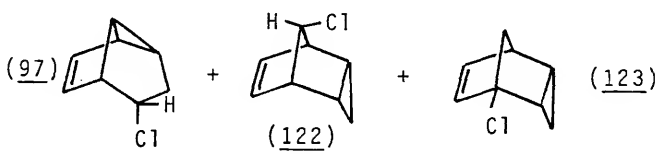
(108) (73) (120) (70) (118)

Both ketone (70) and the cycloheptene ester (118) can be viewed as products derived from the hemi-ketal (120). Attack by water upon the charge rich C_8 position of the tris-homocyclopropenyl cation (73) (*anti* approach) would yield the hemi-ketal (120). Hemi-ketal (120) then has the option of losing methanol to form ketone (70), or, with the assistance of either Ag^+ or proton cleavage of the cyclopropyl ring, rearrange[57] in the manner shown to give the cycloheptene ester (118).

Mention was made earlier of an alternative synthesis of *endo*-6-chlorotricyclo[3.3.0.$0^{2,8}$]oct-3-ene (97). Breslow has reported[58] the generation of 5-halo substituted cyclopentadienes, and in particular, 5-chlorocyclopentadiene (121), by the reaction of cyclopentadienylthallium with n-chlorosuccinimide. Cyclopropene was then bubbled through a solution of (121), and glpc analysis revealed the presence of three minor products and one major product (total yield ca. 25%). The major product (83.7% of product mixture), rearranged chloride (97), was identified by its spectral data and by literature[50] comparisons already discussed.



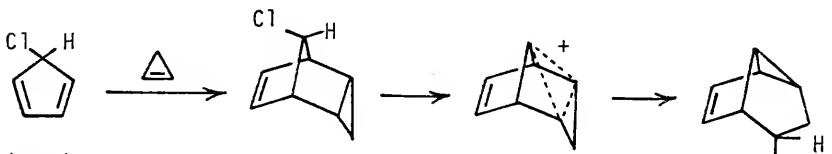
(121)



(122) (123)

Two of three minor products were identified. *Syn*-8-chloro-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene (22), in 8.0% relative yield, was identified from it's PMR spectrum δ[5.81 (2,t), 4.04 (1,m), 2.82 (2,m), 1.62 (2,m), 0.78 (2,m)], and glpc/mass spectrum (140 m/e). 1-Chloro-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene (123), in 6.1% relative yield, was also identified from the PMR spectrum δ[5.80 (2,d), 2.77 (1,m), 2.38 (1,q), ca. 2.04 (1,m), 1.63 (2,m), ca. 0.68 (2, complex)], and glpc/mass spectrum (140 m/e).

Cyclopentadienes substituted in the C_5 position are known[59] to tautomerize readily to the more stable vinyl substituted cyclopentadienes; however, Breslow reported[58a] that his method involving cyclopentadienylthallium reduces this problem. In fact, only one minor product, i.e. (123), could be attributed to tautomerization. *Syn*-chloride (122) appears to result simply from the Diels-Alder addition of cyclopropene to (121) on the chlorine side of the cyclopentadienyl plane.



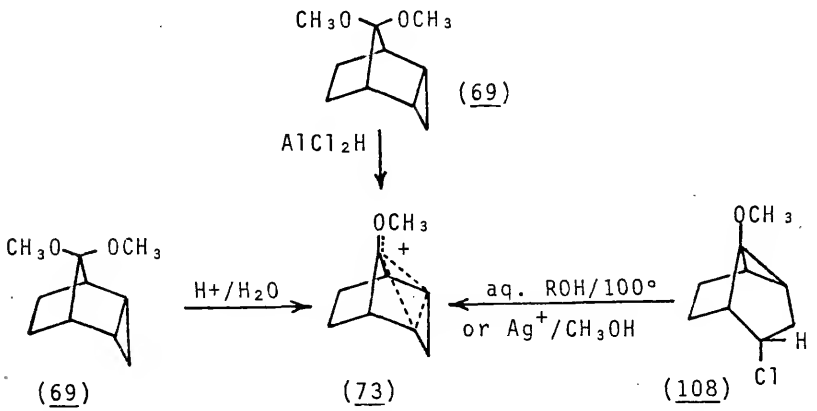
(121) (124) (102) (97)

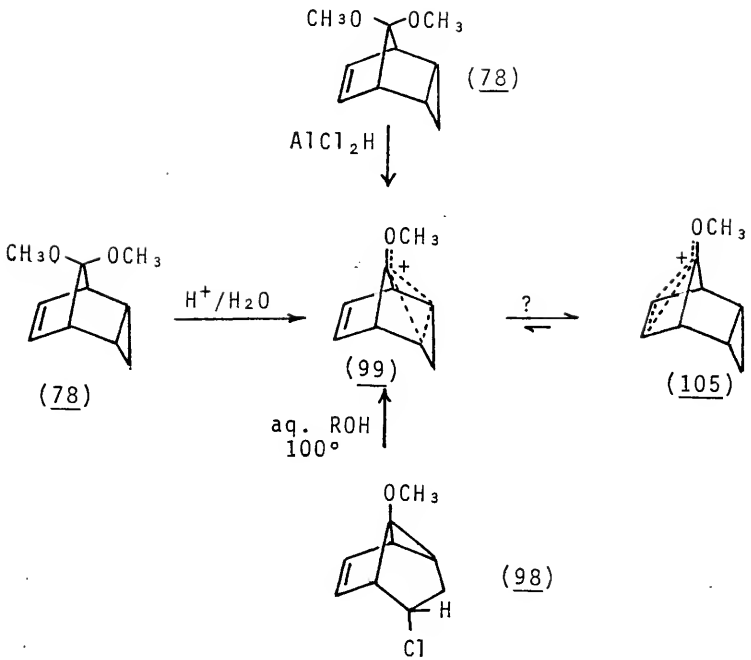
The rearranged chloride (97) appears to be the result of cyclopropene addition to (121) giving the transient *anti*-chloro-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene (124) which, through cyclopropyl assistance and possibly thallium (I) cationic coordination catalysis, would rearrange (probably through a tight ion pair) via the tris-homocyclopropenyl cation (102) to give the major product (97).

In summary, the results presented strongly indicate that the ionic intermediates generated by the reaction of dichloroaluminum hydride with, and the acidic hydrolysis of, the saturated and unsaturated ketals (69) and (78), are the same as those generated by the solvolysis of the saturated and unsaturated rearranged chloro ethers (108) and (98), i.e.,

the 3-methoxy-2,4-ethano- and 3-methoxy-2,4- etheno-tris-homocyclopropenyl cations (73) and (99) respectively. Product studies have also raised the possibility that the unsaturated tris-homocyclopropenyl cation (99) is in equilibrium via a bridge flipping process with the bis-homocyclopropenyl (105).

The electron structure of these ions has been radically altered with respect to the parent ions in that positive charge delocalization is not as extensive with most of the charge localized or concentrated at the methoxyl bridge carbon. The cyclopropyl delocalization may even have been weakened to the point where nucleophiles are able to penetrate and attack the bridge from the *syn* face of the bridge. This electronic effect, not steric bias, is thus the overwhelming factor in determining the orientation and stereochemistry of solvent or nucleophilic attack.




CH3O
OCH3
(78)
AlCl2H
H+/H2O
OCH3
(99)
?
(105)
aq. ROH
100°
(98)
Cl
H

CHAPTER III

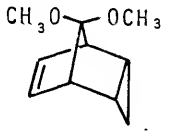
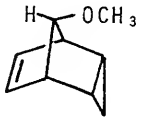
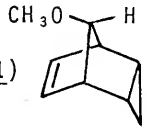
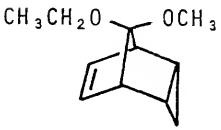
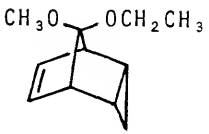
PMR Studies

Syn and *Anti* Chemical Shifts of Alkoxyl Groups at C_8 in the Tricyclo[3.2.1.$0^{2,4}$]octanyl-octenyl Systems

It is advantageous at this point to summerize the PMR chemical shifts of methoxy and ethoxy groups substituted at the C_8 position of the tricyclo[3.2.1.$0^{2,4}$]octane and tricyclo-[3.2.1.$0^{2,4}$]oct-6-ene systems. Much of the work already presented depends upon the correct *syn* or *anti* assignment at C_8 of these alkoxy groups.

Authors seem to have been hesitant to declare in the literature their assignments of the methoxyl chemical shifts of the saturated and unsaturated ketals, (69) and (78). Pincock has stated[22] that the difference in chemical shift caused by the field effect of the *endo* cyclopropyl ring in saturated ketal (69) upon the *syn* methoxyl relative to the *anti* methoxyl group is 0.11 ppm (observed here as 0.10 ppm). He compared[22] this value with the shift induced by the double bond upon the *syn* methoxyl in norbornene dimethyl ketal (75), i.e. 0.07 ppm, relative to the *anti*-methoxyl group, and concludes that, within the specified geometry of these systems, the cyclopropyl group relative to the double bond, has the greater effective ability to deshield. This fact is demonstrated in Table II if one examines the methoxyl shifts for the *syn* and *anti* unsaturated ethers (95) and (101). The

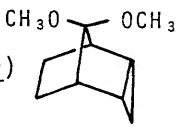
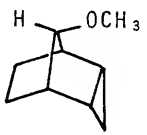
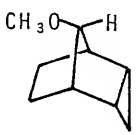
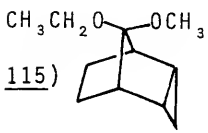
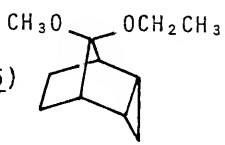
Table II. *Syn* and *Anti* C_8 Alkoxyl Chemical Shifts in Tricyclo[3.2.1.$0^{2,4}$]octenyl Systems

	$\delta anti$	δsyn	$\Delta syn-anti$, ppm
 (78)	3.13	3.27	.14
 (95)	-	3.27	.06
 (101)	3.21	-	
	3.38 ($-CH_2$)	3.27	.14 ($-OCH_3$)
 (113)	3.13	3.53 ($-CH_2$)	.15 ($-OCH_2CH_3$)

syn-methoxyl of (95) is deshielded by the cyclopropyl group by .06 ppm more than the double bond deshielding of the *anti*-methoxyl of (101). The observed *syn* and *anti*-methoxyl signals for the mixed ketals (112) and (113) are identical to the *syn*

and *anti*-methoxyl signals of the parent compound, unsaturated dimethoxy ketal (78), confirming the epimeric assignments of (112) and (113). An inspection of Table III listing the chemical shifts of the saturated analogs also confirms the epimeric assignments for the saturated ketals, (69), (115) and (116).

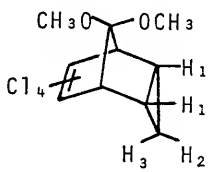
Table III. *Syn* and *Anti* C_8 Alkoxyl Chemical Shifts in Tricyclo[3.2.1.$0^{2,4}$]octanyl Systems

	$\delta anti$	δsyn	$\Delta syn-anti$, ppm
 (69)	3.21	3.31	.10
 (89)	-	3.33	.06
 (90)	3.27	-	
 (115)	3.47 ($-CH_2$)	3.33	.11 ($-OCH_3$)
 (116)	3.22 ($-CH_2$)	3.59 ($-CH_2$)	.12 ($-OCH_2CH_3$)

Computer Analyzed PMR Spectra

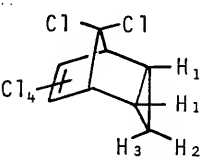
In an effort to add to the relatively scarce PMR data concerning the cyclopropyl group in the tricyclo[3.2.1.$0^{2,4}$]-octyl systems, the four polychlorinated *endo* cyclopropene Diels-Alder adducts, (88), (125), (126), and (127) were prepared. Thoroughly degassed carbon tetrachloride solutions of these compounds were sealed under vacuum in NMR tubes. The individual spectra were expanded to 50 Hz and the absorptions calibrated via the TMS side-band technique. The observed absorption data was applied to a modified LAOCOON III[60] computer program, and coupling signs were based on convention.

(88)



The preparation of 1,5,6,7-tetrachloro-8-dimethoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene (88) has already been described in this text. The proton chemical shifts and standard deviations were reported for a 1M solution (CCl_4) in Hz as follows: H_1, -105.317±0.015; H_2, -53.263±0.017; H_3, -24.715±0.016. Coupling constants were: $J_{1,2}$=7.073±0.020; $J_{1,3}$=3.469±0.018; $J_{2,3}$= -7.434±0.023.

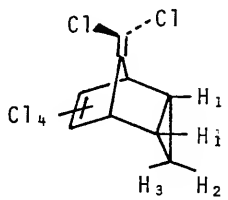
(125)



The addition of cyclopropene to hexachlorocyclopentadiene gave 1,5,6,7,8,8-hexachloro-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene

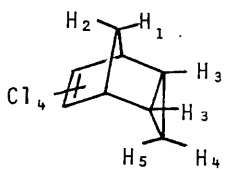
(125) in 92.6% yield. The PMR and infra-red spectra were in agreement[61] with the assigned structure, as was the elemental analysis. The computer analyzed proton chemical shifts for a 1M solution (CCl_4) were reported in Hz as: H_1, -120.777±0.012 Hz; H_2, -77.408±0.013; H_3, -46.877±0.012. The coupling constants were revealed as: $J_{1,2}$=7.175±0.014; $J_{1,3}$=3.493±0.014; $J_{2,3}$= -7.707±0.017.

(126)



1,5,6,7-Tetrachloro-8-dichloromethylene-*endo*-tricyclo-[3.2.1.$0^{2,4}$]oct-6-ene (126) was prepared in 80.4% yield from the addition of cyclopropene to hexachlorofulvene.[62] The PMR and infra-red spectra agreed with the assigned structure, as did the mass spectrum (322 m/e) and elemental analysis. The computer analyzed PMR spectrum gave the chemical shifts of a 0.51 M solution (CCl_4) in Hz as: H_1, -121.390±0.009; H_2, -67.772±0.010; H_3, -39.458±0.012. The coupling constants were determined to be: $J_{1,2}$=7.025±.011; $J_{1,3}$=3.090±.011; $J_{2,3}$= -7.804±.014.

(127)



The addition of cyclopropene to 1,2,3,4-tetrachlorocyclopentadiene[49] gave 1,5,6,7-tetrachloro-*endo*-tricyclo-[3.2.1.$0^{2,4}$]oct-6-ene (127) in 77.7% yield. The PMR and infra-red spectra, along with the elemental analysis, confirmed the structure.[61] The computer analyzed PMR spectrum of a 1M solution (CCl_4) gave the proton chemical shifts in Hz as follows: H_1, -185.844±0.020; H_2, -149.271±0.017; H_3, -119.841±0.018; H_4, -56.641±0.018; H_5, -34.716±0.018. The coupling constants were reported as: $J_{1,2}$= -6.707±0.026; $J_{1,3}$= -0.246±0.026; $J_{1,4}$=0.298±0.028; $J_{2,3}$= -0.290±0.020; $J_{2,4}$= 2.528±0.025; $J_{3,4}$= 7.218±0.021; $J_{3,5}$= 3.170±0.020; $J_{4,5}$= -7.503±0.024. The noteworthy (2.5 Hz) extended "W"[63] coupling of H_2 and H_4 protons, and the small (0.30 Hz) coupling of H_1 and H_4 has potential use in confirming *syn* and *anti* assignments involving mono substitution at the bridge C_8 position.

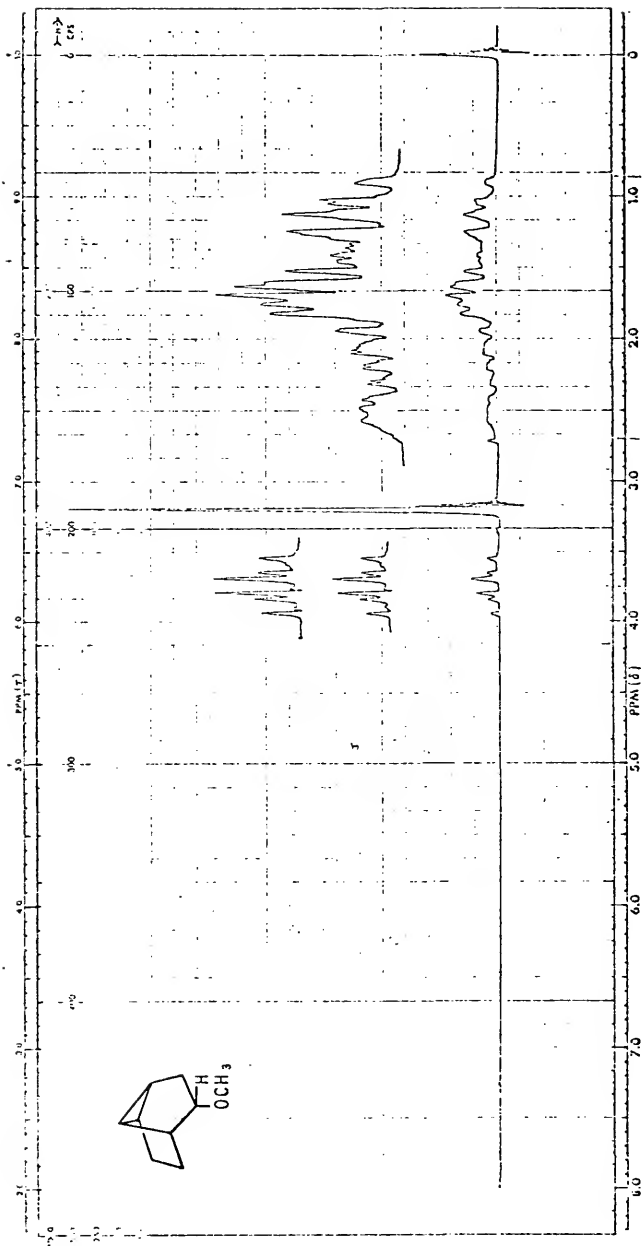


Figure 1. *endo*-4-Methoxytricyclo[3.3.0.0^{2,8}]octane, (92).

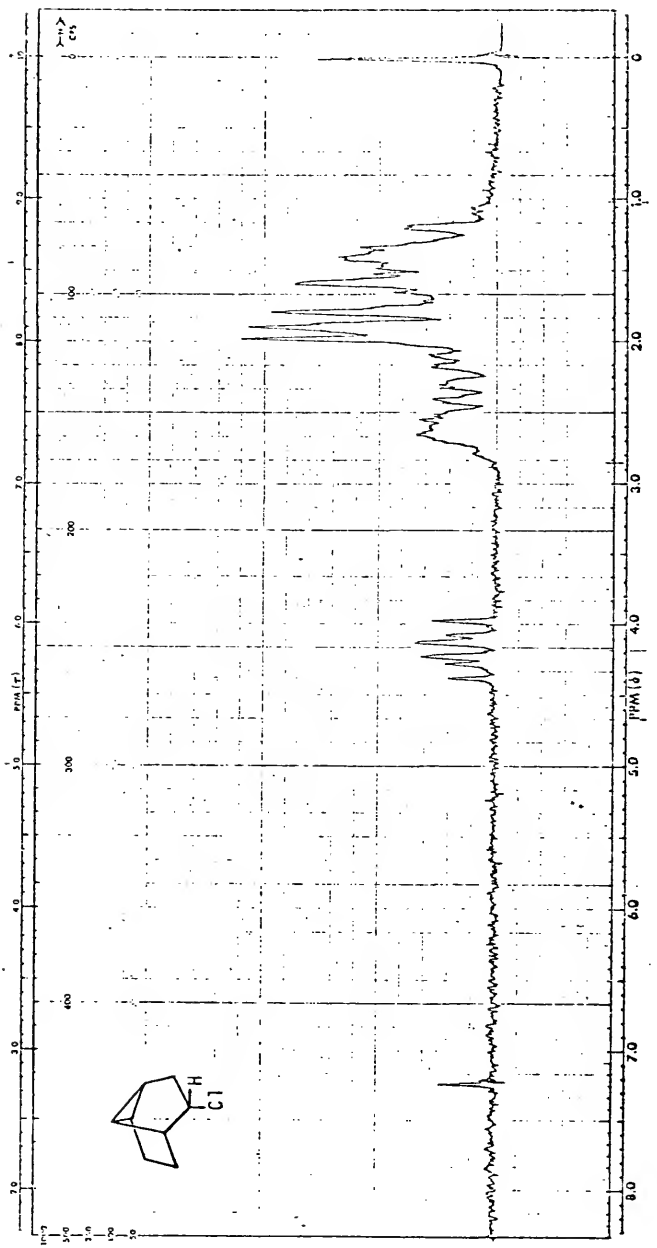


Figure 2. *endo*-4-Chlorotricyclo[3.3.0.0^{2,8}]octane, (93).

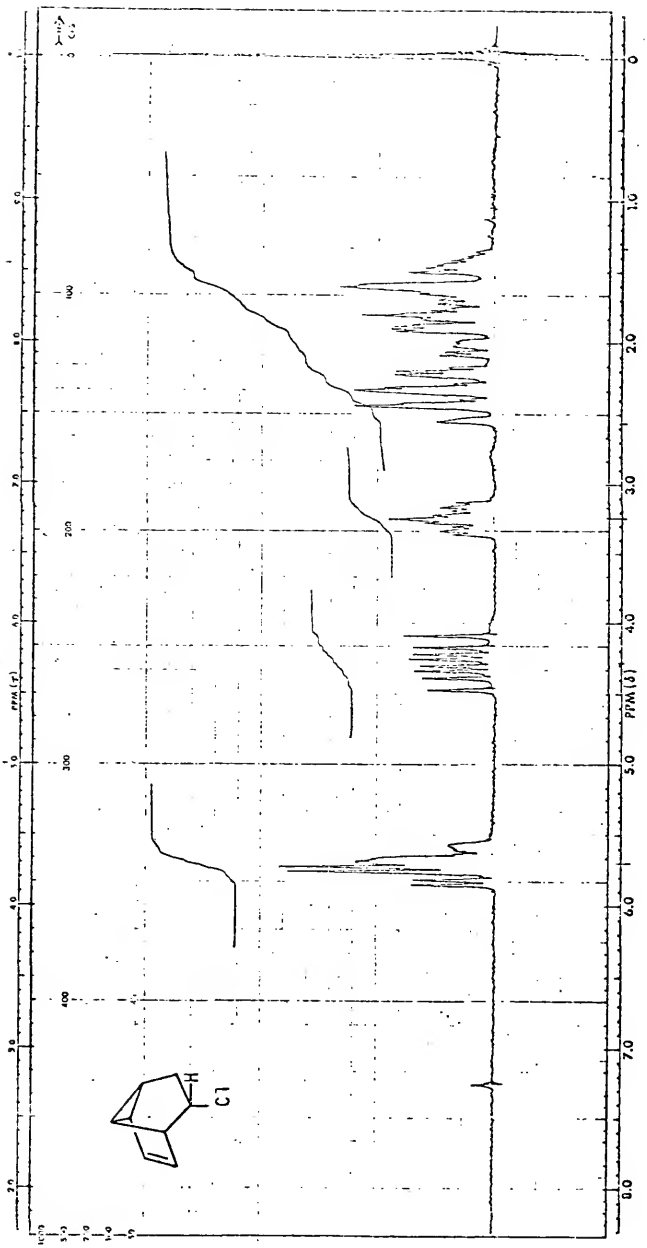


Figure 3. *endo*-6-Chlorotricyclo[3.3.0.0^{2,8}]oct-3-ene, (97).

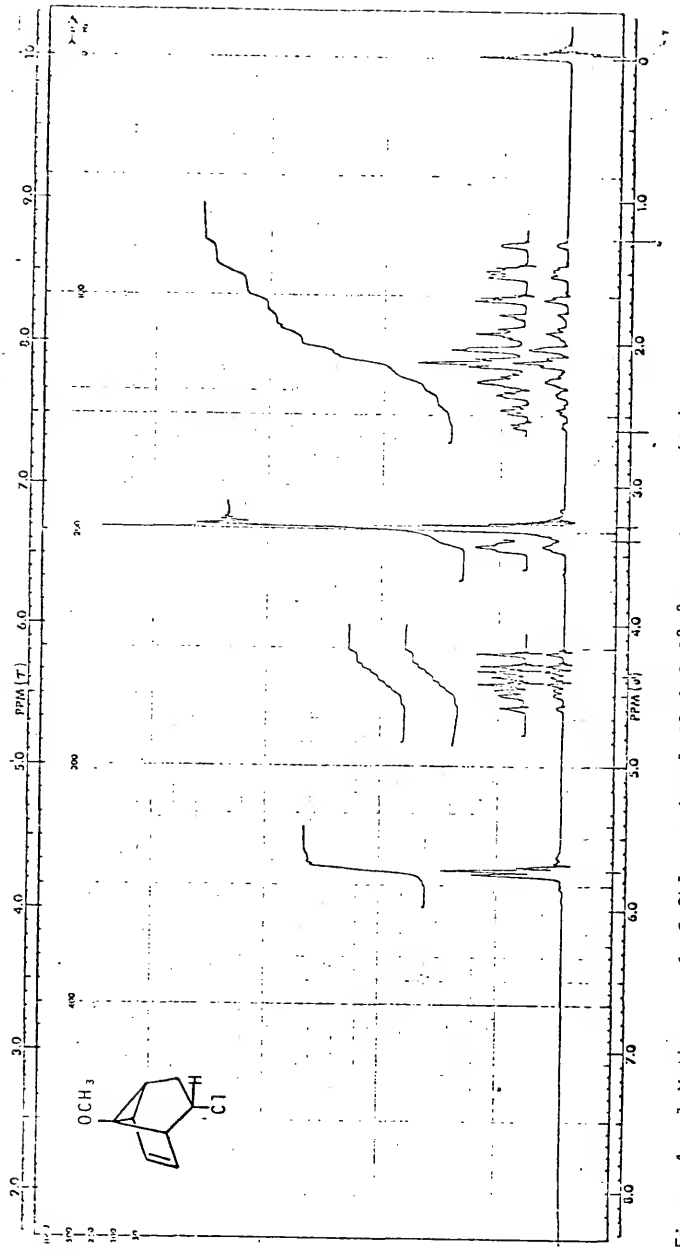


Figure 4. 1-Methoxy-*endo*-6-Chlorotricyclo[3.3.0.0^{2,8}]oct-3-ene, (98).

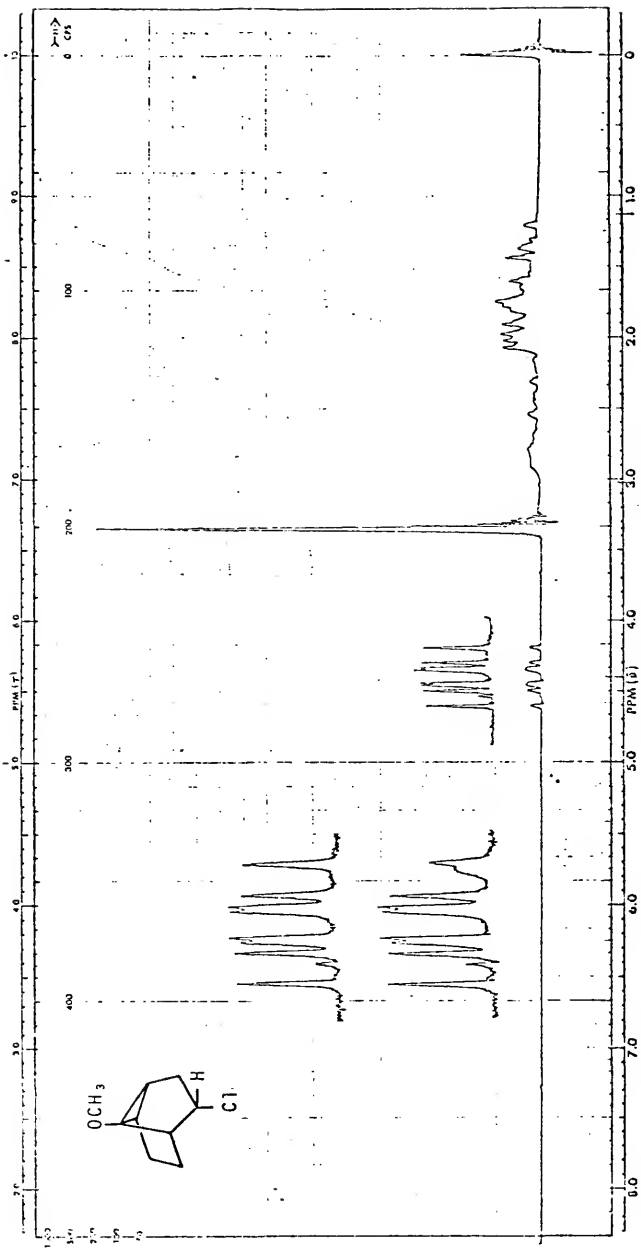


Figure 5. 1-Methoxy-*endo*-4-chlorotricyclo[3.3.0.0^{2,8}]octane, (108).

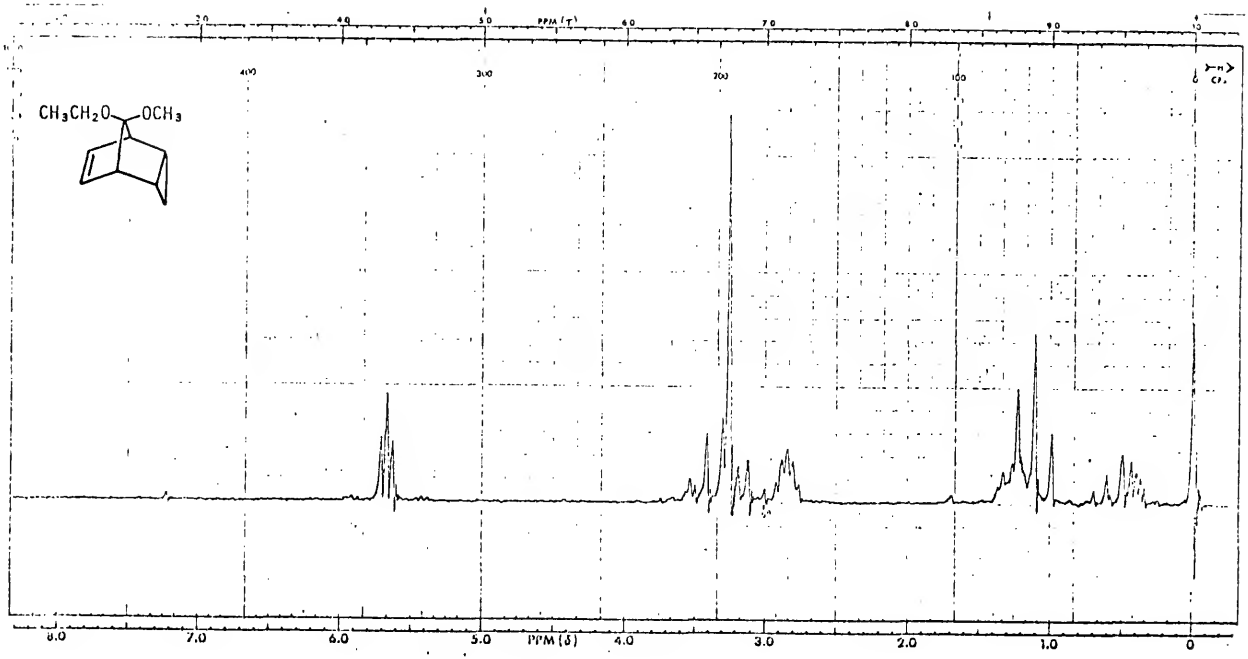


Figure 6. *anti*-8-Ethoxy-*syn*-8-methoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene, (112).

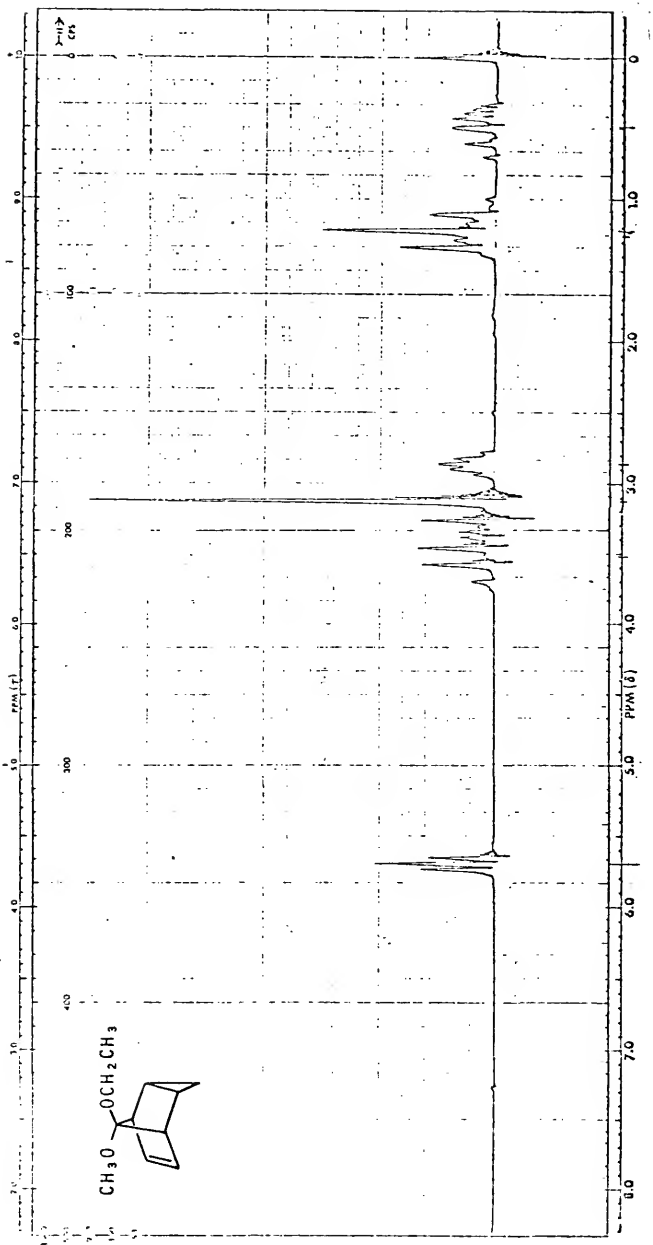


Figure 7. *anti*-8-Methoxy-*syn*-8-ethoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene, (113).

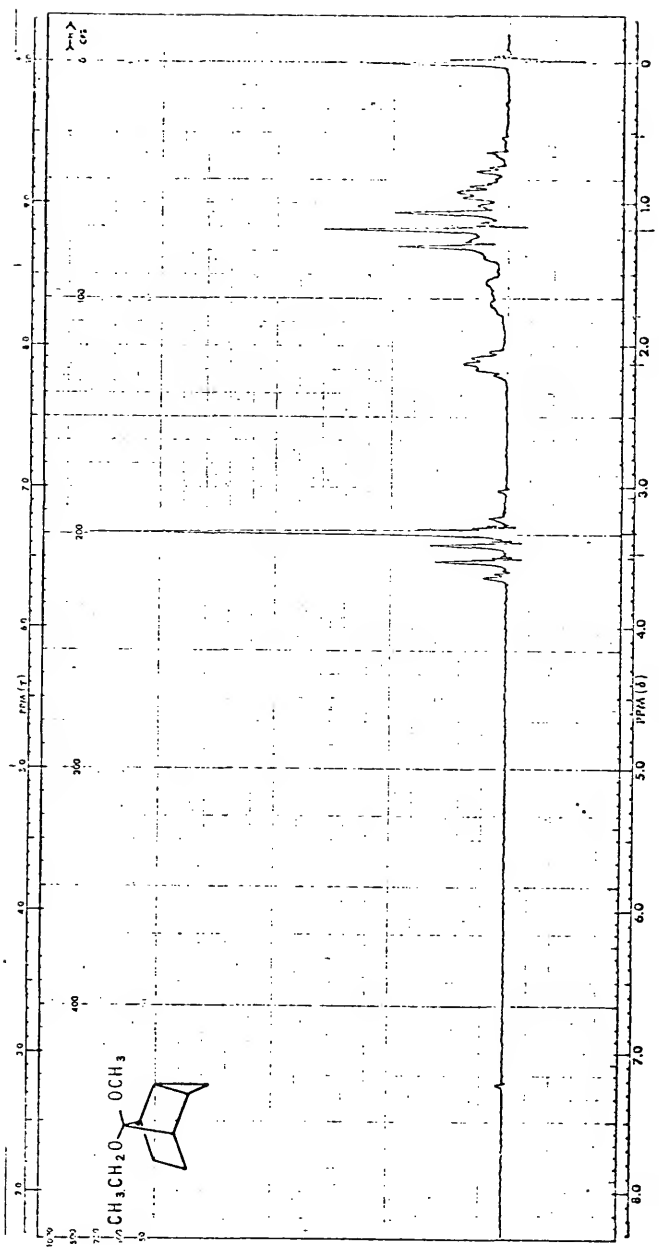


Figure 8. *anti*-8-Ethoxy-*syn*-8-methoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]octane, (115).

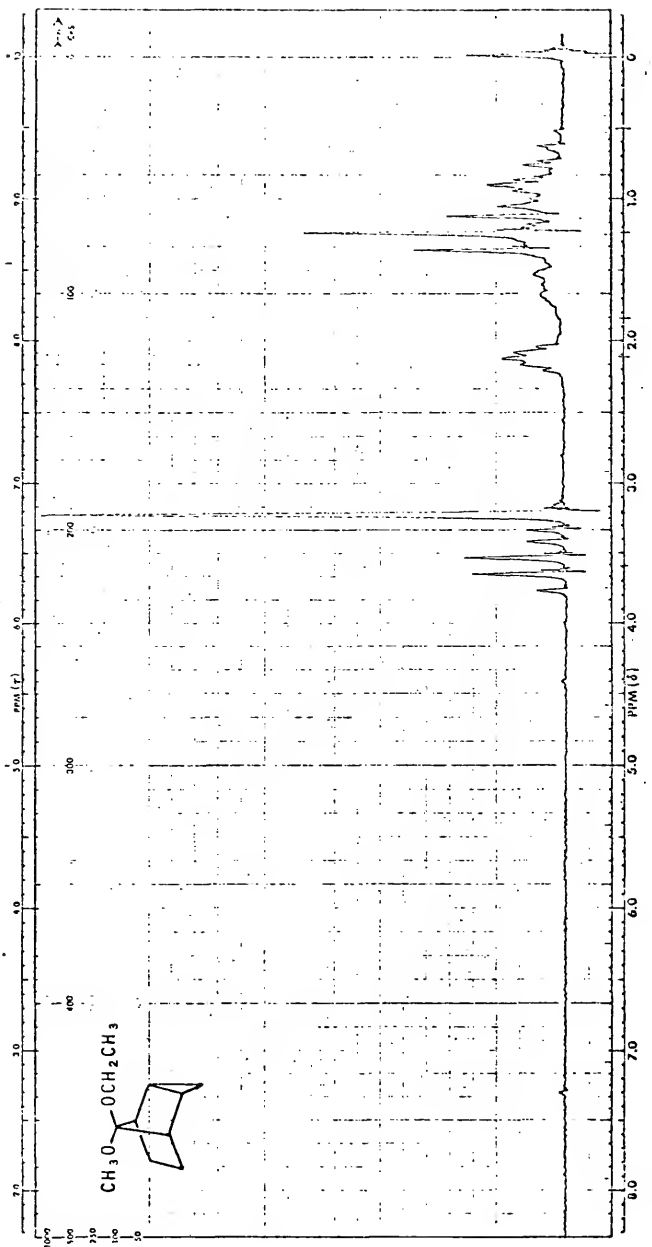


Figure 9. *anti*-8-Methoxy-*syn*-8-ethoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]octane, (116).

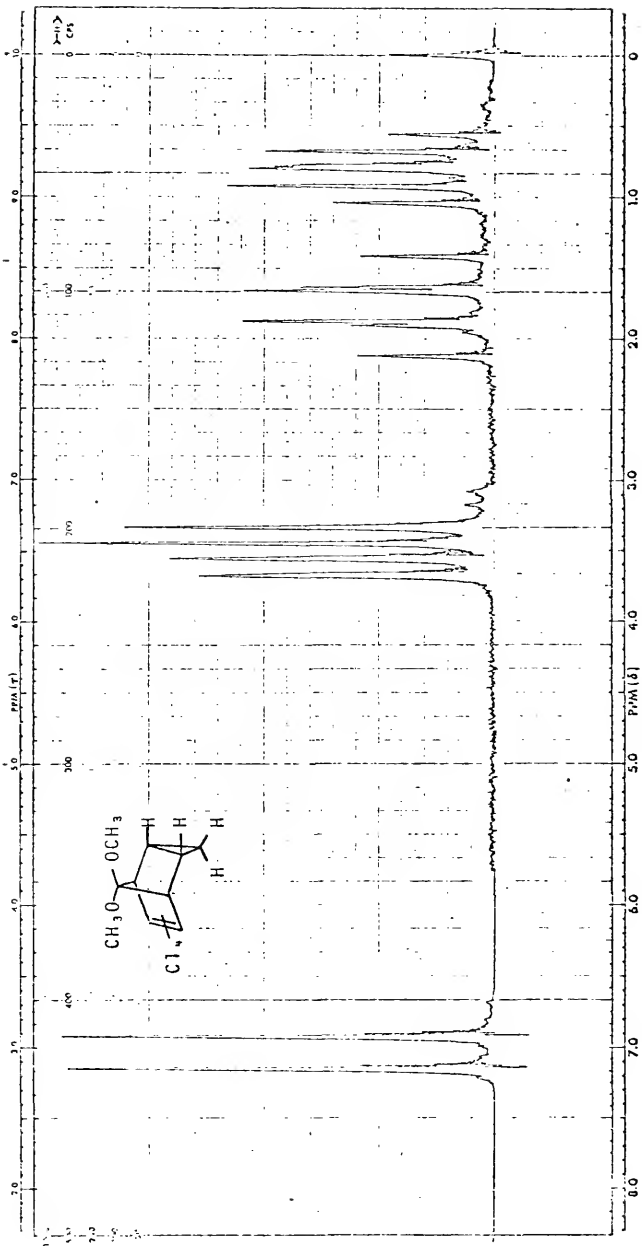


Figure 10. 1,5,6,7-Tetrachloro-8,8-dimethoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene, (88), at 250 Hz.

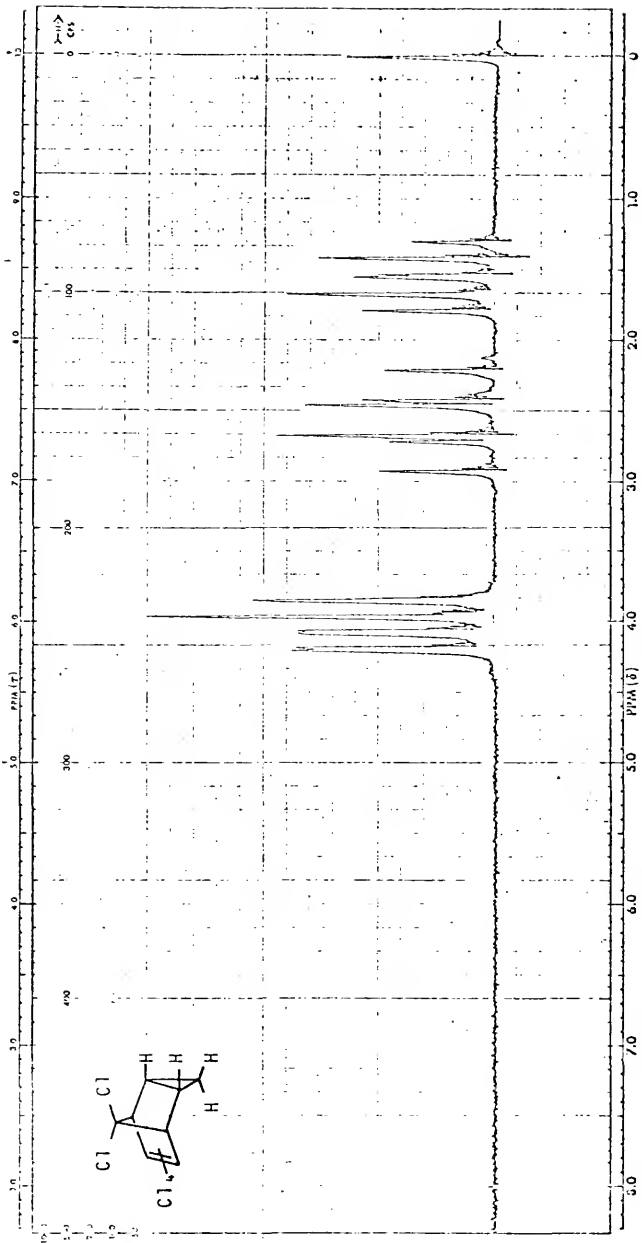


Figure 11. 1,5,6,7,8,8-Hexachloro-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene, (125), at 250 Hz.

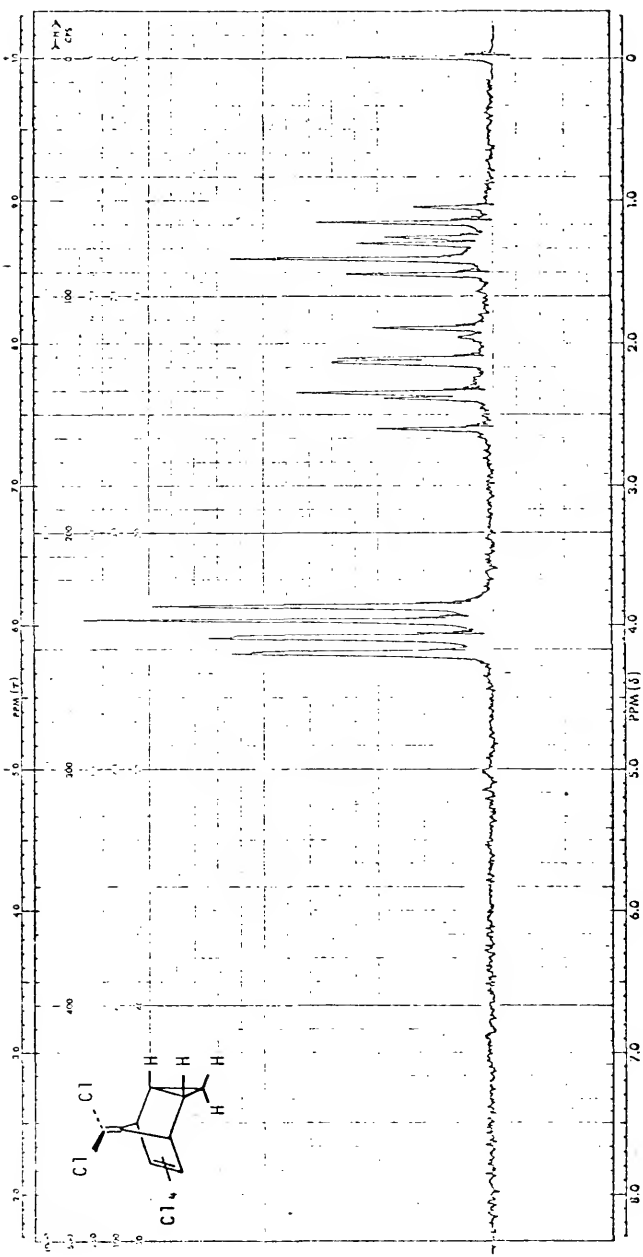


Figure 12. 1,5,6,7-Tetrachloro-8-dichloromethylene-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene, (126), at 250 Hz.

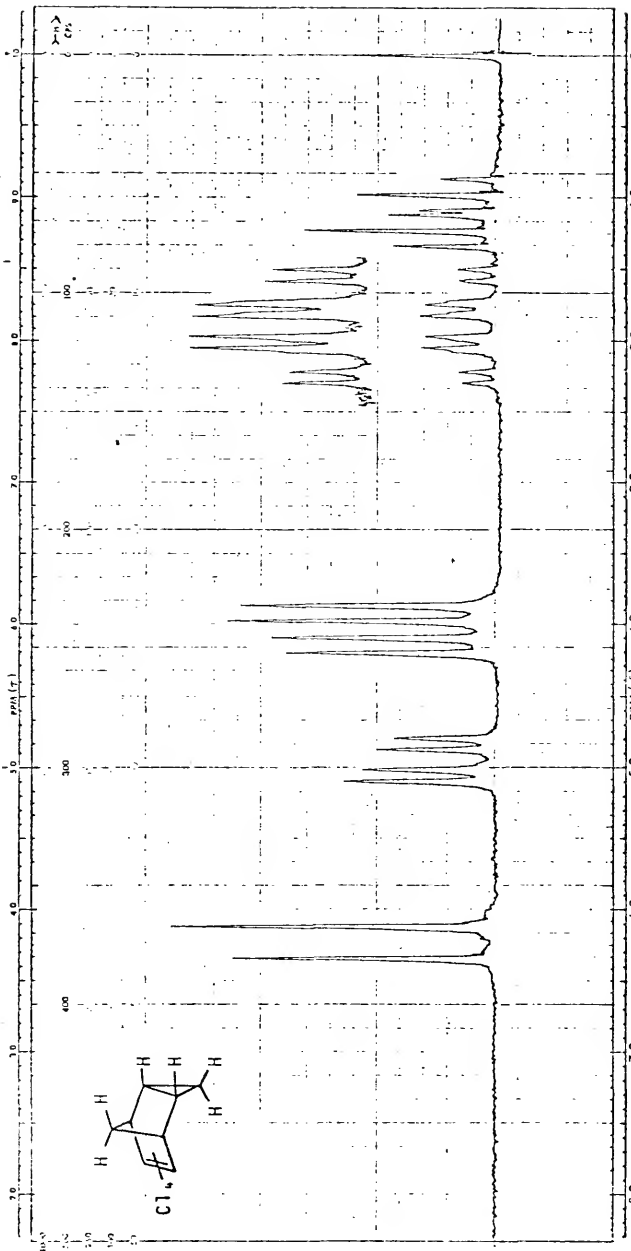


Figure 13. 1,5,6,7-Tetrachloro-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene, (127), at 250 Hz.

CHAPTER IV

Experimental

General

Melting points were determined on a Thomas-Hoover unimelt capillary melting point apparatus and are uncorrected. Elemental analyses were performed by Atlantic Microlab, Inc., Atlanta, Georgia.

Vapor Phase Chromatography

The analytical gas/liquid phase chromatography was performed with an Aerograph Hy-Fi 600-D instrument with a flame ionization detector, using column A, which consisted of 15% FFAP on Chrom W, AW, DMCS, 1/8" x 5', with a helium flow rate of 300 cc/min. Column B consisted of a 100' x 1/100" DEGS capillary column fitted on a Varian Aerograph Series 1400 flame ionization instrument. For preparative work, a Varian Aerograph model 90-D with a thermal conductivity detector was employed using one of two columns: column C which consisted of 15% FFAP on Chrom W, AW, DMCS, 4.5' x 1/4", helium flow ca. 140 cc/min.; column D which was packed with 20% DEGS on 45/60 Chrom W, 10' x 1/4", helium flow ca. 100 cc/min.

Spectra

Infrared spectra were determined on either a Beckman IR-10 or a Perkin-Elmer 137 Sodium Chloride Spectrometer. Proton

magnetic resonance spectra were recorded on Varian A-60A instrument. Low resolution mass spectra were provided by a Perkin-Hitachi RMU-6E instrument. High resolution spectra were determined by a AEI-MS-30 instrument which was also used in conjuction with a Pye Unicam Series 104 Chromatograph utilizing a 5' x 1/4" SE-30 column.

Generation of Cyclopropene

A slightly modified procedure of the original method reported by Closs and Krantz[64] was employed. A typical run is as follows:

To a magnetically stirred suspension of 50 grams of fresh sodium amide in 70 ml of dry mineral oil at 85-90° were added dropwise (1 drop/4 sec.) approximately 75 ml of 3-chloropropene. A slow stream of dry nitrogen gas transported the evolved cyclopropene through a Friedrich condenser (water cooled), followed by a 4N sulfuric acid trap (200 ml) and then onto the reaction vessel via a scintered glass outlet.

Preparation of 1,2,3,4-Tetrachloro-5,5-dimethoxycyclopenta-1,3-diene (87)

To a mechanically stirred solution of 205 grams of hexachlorocyclopentadiene (0.751 mole, Aldrich) in 300 ml absolute methanol was added a solution of 112 grams of potassium hydroxide (2.0 moles) in 300 ml absolute methanol. The addition was carried out at a rate commensurate with maintaining gentle reflux, and was followed with continued stirring at room temperature for *ca.* ten hours. The reaction mixture was filtered to remove precipitated potassium chloride, and

solvent was removed under water aspirator pressure after drying with anhydrous magnesium sulfate. Vacuum distillation (b.p. 63.0-65.5°/0.05 mm) yielded 115 grams (0.436 mole, 58.0%) of pale yellow oil. The spectral data were in agreement with those previously reported.[46]

Preparation of 1,2,3,4-Tetrachloro-5,5-diethoxycyclopenta-1,3-diene

The synthetic procedure followed is identical to the preparation of the dimethoxy analog (87) already described. Using 205 grams (0.751 mole) of hexachlorocyclopentadiene, 112 grams (2.0 moles) of potassium hydroxide, and 600 ml total absolute ethanol, 107.4 grams (0.389 mole, 51.8%) of the diethoxy ketal was isolated after vacuum distillation (b.p. 103-105°/2.6 mm). Spectral data were in accord with literature values.[65]

Preparation of 1,5,6,7-Tetrachloro-8,8-diemthoxy-*endo*-Tricyclo [3.2.1.$0^{2,4}$]oct-6-ene (88)

Cyclopropene was passed through a rapidly stirred solution of 40.0 grams (0.152 mole) of 1,2,3,4-tetrachloro-5,5-dimethoxycyclopenta-1,2-diene (87) in ca. 250 ml of petroleum ether (20-40°) at ambient temperature. The reaction was followed by PMR monitoring of the respective methoxyl methyl signals and was found to be complete after ten hours. The solvent was removed by passing a stream of nitrogen over the solution, yielding 34 grams (0.112 mole, 73.7%) of white crystals (m.p. 63-66°, lit. m.p. 68-70°). Spectral data were in agreement with literature values,[21a,22,39] and a computer analyzed PMR spectrum is presented in Chapter III.

Preparation of 1,5,6,7-Tetrachloro-8,8-diethoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene

The same procedure applied above for the preparation of the dimethoxy adduct (88) was employed for the diethoxy analog. From 105 grams (0.380 mole) of 1,2,3,4-tetrachloro-5,5-diethoxy-cyclopenta-1,3-diene, 98.6 grams (0.297 mole, 78.1%) of the cyclopropene adduct was isolated after vacuum distillation as a yellow liquid (b.p. 136-145°/1.25 mm). The analytical sample was isolated from preparative glpc column C, at 130°. The PMR spectrum ($CDCl_3$) consisted of two overlapping two proton quartets at δ3.95 and 3.83, a two proton quartet at 1.78, two overlapping three proton triplets at 1.26 and 1.14, a one proton sextet at 0.90, and a one proton quintet at 0.40. The infra-red (neat) gave absorption bands at 2990 (m), 2890 (w), 1597 (m), 1275 (m), 1160 (s), and 1025 (m) cm^{-1}.

Anal. Calcd. for $C_{12}H_{14}Cl_4$: C, 43.40; H, 4.25; Cl, 42.71.
Found: C, 43.43; H, 4.28; Cl, 42.65.

Preparation of 8,8-Dimethoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene (78)

The dechlorination of ketal (88) was accomplished via Gassman's procedure.[47] Into a 1l flask fitted with a mechanical stirrer, nitrogen inlet, and water-cooled Friedrich condenser, were added 25.0 grams (0.0822 mole) tetrachloroketal (88), 125 ml *tert*-butanol, 325 ml tetrahydrofuran, and chopped sodium (39.0 grams, 1.70 g-atoms). The solution was stirred and heated to gentle reflux for ten hours, cooled, and filtered through wire gauze to remove unreacted sodium. The filtered solution was added to 500 ml of water, followed by the addition of

250 ml of brine and 250 ml of ether. The organic layer was separated and the aqueous layer was extracted (6 x 100 ml) with ether. The combined ether fractions were dried over anhydrous magnesium sulfate, and the bulk of the solvent was distilled utilizing a steam bath and a 2' Vigreaux column. Traces of solvent were removed on a rotary evacuator. Vacuum distillation (30-35°/4mm) yielded 7.62 grams (0.0458 mole, 56.0%) of light yellow product, whose spectral analysis agreed with that previously reported.[21a,22,39]

Preparation of 8,8-Diethoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene

The dehalogenation procedure employed for the dimethoxy analog (88) was followed using, in this case, 98 grams (0.295 mole) of 1,5,6,7-tetrachloro-8,8-diethoxy-*ento*-tricyclo-[3.2.1.$0^{2,4}$]oct-6-ene, 450 ml of *tert*-butanol, and 140 grams (3.59 g-atoms) of chopped sodium metal. Due to the generation of a considerable amount of tar, work-up was more difficult and required the use of hexane to effect separation. Vacuum distillation (b.p. 65-70°/1.9 mm) gave 18.0 grams (0.0927 mole, 31.4%) of a pale yellow oil. The analytical sample was isolated on preparative glpc column D at 145° (7 min.). The PMR spectrum ($CDCl_3$) exhibited a two proton triplet at δ5.67, two overlapping two proton quartets at 3.53 and 3.38, a two proton multiplet at 2.84, two overlapping three proton triplets at 1.20 and 1.09 which obscure a two proton multiplet at ca. 1.26, and two overlapping one proton multiplets at ca. 0.49. The calculated mass for $[C_{12}H_{18}O_2]^+$ is 194.1306, while accurate mass measurement (70 eV) gave 194.1303, for an error of -1.39

ppm. The infra-red (neat) gave absorption bands at 3060 (m), 2970 (s), 2925 (m), 2870 (m), 1565 (w), 1260 (s), and 1100 (s) cm^{-1}.

Anal. Calcd for $C_{12}H_{18}O_2$: C, 74.19; H, 9.34.

Found: C, 74.26; H, 9.36.

Preparation of 8,8-Dimethoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]-octane (69)

A stirred suspension consisting of 3.0 grams (17.8 mmole) of unsaturated dimethoxy ketal (78), 0.268 gram of 10% Pd/C catalyst, and 150 ml of absolute metahnol was subjected to a partial positive pressure of hydrogen gas. After about 3.5 hours, 460 ml of hydrogen were consumed (440 ml theoretical), and the catalyst was removed by filtration. The solvent was removed at room temperature under water aspirator pressure. Vacuum distillation (b.p. 62-69°/12 mm) produced 1.76 grams (10.5 mmole, 58.8%) of saturated ketal (69) as a colorless oil whose spectral data agreed with earlier reports.[21a,22,39]

Preparation of 8,8-Diethoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]octane

The method of catalytic hydrogenation of the dimethoxy ketal (69) was employed to prepare the diethoxy ketal. The reaction mixture consisted of 1.079 grams (5.55 mmole) of unsaturated diethoxy ketal, 0.100 gram of 10% Pd/C, and 25 ml of absolute ethanol. Hydrogen absorption amounted to 140 ml as compared to 125 ml calculated for the theoretical. The saturated product was isolated as a colorless oil via preparative glpc column D at 130° (10 min), giving 0.549 gram (2.80 mmole, 50.5%) of product. The PMR spectrum ($CDCl_3$) consisted of two overlapping two proton quartets at δ3.61 and 3.49, a

two proton multiplet at 2.13, and a fourteen proton complex from 1.82 to 0.52, which includes two overlapping three proton triplets at 1.23 and 1.17. The mass spectrum (70 eV) gave peaks at m/e (rel. intensity) 129 (100), 101 (47.0), and 73 (68.0). The calculated mass for $[C_{12}H_{20}O_2]^{+\cdot}$ is 196.1462, while accurate mass measurement gave 196.1460, for an error of 1.53 ppm.

Anal. Calcd. for $C_{12}H_{20}O_2$: C, 73.43; H, 10.27.
Found: C, 73.50; H, 10.30.

Preparation of *endo*-Tricyclo[3.2.1.$0^{2,4}$]octan-8-one (70)

A solution of 42.60 grams (0.253 mole) of saturated dimethoxy ketal (69), 4.7 ml (.261 moles) water, and 110 ml glacial acetic acid was heated at 69° with stirring for 24 hours. The reaction mixture was cooled with an ice-water bath, and a chilled solution of 72.5 grams sodium hydroxide in 440 ml water was slowly added to affect neutralization of the acetic acid. Extraction with ether (5 x 130 ml), drying with anhydrous magnesium sulfate, removal of solvent, and vacuum distillation (b.p. 65-70°/0.2 mm) yielded 29.4 grams (0.241 mole, 92.2%) of ketone (70) as a slushy semi-solid with spectral properties in agreement with previously reported data.[21a,22,39]

Preparation of *syn*-8-Methoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]octane 89 from 8,8-Dimethoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]octane (69)

Reaction procedure followed was that reported by Eliel.[48a] Into a dry 300 ml flask was placed 6.66 grams (0.05 mole) of anhydrous aluminum chloride, and, with drying tube in place,

the flask was cooled with an external ice-water bath. Chilled anhydrous diethyl ether (50 ml) was cautiously added with stirring, and was followed thirty minutes later by the addition of 0.450 gram (0.0125 mole) of lithium aluminum hydride dissolved in 20 ml ether. After another thirty minutes, 4.21 grams (0.025 mole) of saturated methoxy ketal (69), dissolved in 50 ml of ether, was added dropwise to the suspension. Upon completion of the last addition, the ice-water bath was removed and the reaction mixture was stirred for 1.75 hours at room temperature. The reaction was again cooled, and subsequently quenched with 50 ml of 10% sulfuric acid. After filtration, the ether and aqueous layer were separated, and the aqueous layer was extracted with ether (3 x 50 ml). The combined ether fractions were dried over anhydrous potassium carbonate and magnesium sulfate, followed by solvent removal on rotary evacuator, to yield 3.02 grams of 94.7% glpc pure (0.0207 mole, 82.2%) *syn*-methyl ether (89). The analytical sample was collected via preparative glpc on column D at 136° (6 min.). The PMR spectrum ($CDCl_3$) revealed a one proton multiplet at δ3.82, a three proton singlet at 3.34 a broadened two proton multiplet at 2.18, and an eight proton complex from 1.67 to 0.68. The mass spectrum (70 eV) gave peaks at m/e (rel. intensity) 138 (9.0), 106 (20.5), 91 (23.0), 84 (77.5), and 71 (100). The infra-red (neat) exhibited absorption bands at 3072 (m), 3035 (s), 2960 (s), 2880 (s), 2825 (s), 1480 (s), 1370 (s), 1210 (s), 1135 (s), 1105 (s), and 1008 (s) cm^{-1}.

Anal. Calcd. for $C_9H_{14}O$: C, 78.21; H, 10.21.

Found: C, 78.16; H, 10.22.

Glpc/mass spectral analysis of the above reaction mixture (5' SE-30, 100°) revealed, in order of product elution from the column, the following data: (a) 0.8%. (b) 94.7%; *syn*-ether (89), data above. (c) 0.9%; m/e (rel. intensity) 136 (51.0), 121 (100), 91 (86.5), 79 (6.5), 78 (12.5), 77 (19.5). (d) 1.8%; 128 (5.0), 110 (22.2), 95 (27.8), 85 (33.7), 69 (43.0), 78 (58.5), 77 (47.0), 57 (100), 56 (25.0), and 54 (61.0). (e) 1.7%; 179 (43.0), 139 (82.0), 107 (61.0), and 79 (100.0).

Reaction of 8,8-Dimethoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene (78) with 4:1 Molar Ratio Aluminum Chloride/Lithium Aluminum Hydride

The reaction procedure was developed by Eliel.[48a] Into a dry 300 ml flask was charged 6.66 grams (0.05 mole) of anhydrous aluminum chloride. After cooling with an external ice-water bath, 50 ml of chilled, anhydrous diethyl ether was slowly added, followed in 20 minutes by 0.450 gram (0.0119 mole) of lithium aluminum hydride in 30 ml ether. After a further 20 minute stirring period, 4.32 grams (0.0260 mole) of unsaturated dimethyl ketal (78), dissolved in 50 ml of ether, was slowly added and the reaction mixture subsequently stirred at room temperature for 1.75 hours. The reaction mixture was again cooled and quenched with 50 ml of 10% sulfuric acid. The ether and aqueous layers were separated, the aqueous layer extracted with ether (3 x 50 ml), and the combined ether layers dried over anhydrous potassium carbonate

and magnesium sulfate. After solvent removal, 3.96 grams of a pale-yellow oil was recovered and subjected to preparative glpc on column D at 124°. Yield precentages are based on relative peak areas of the four components detected.

1) *syn*-8-Methoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene (95), 76.5%; 6.5 minutes. The PMR spectrum ($CDCl_3$) consisted of a two proton multiplet from δ0.53-0.94, a two proton multiplet from 1.26-1.57, a two proton multiplet from 2.66-2.88, a three proton singlet at 3.27, a one proton multiplet at 3.50, and a two proton triplet at 5.61. The mass spectrum (70 eV) showed peaks at m/e (rel. intensity) 136 (10.3), 135 (17.9), 122 (38.0), 104 (100), 91 (100), 77 (92.3) and 44 (100). The infra-red (neat) showed absorption bands at 3060 (s), 2990 (s), 1570 (w), 1440 (m), 1220 (s), and 1100 (s) cm^{-1}.

Anal. Calcd. $C_9H_{12}O$: C, 79.37; H, 8.88.

Found: C, 79.37; H, 8.92.

2) *endo*-6-Methoxytricyclo[3.3.0.$0^{2,8}$]oct-3-ene (96), 3.50%, 80 minutes. The PMR spectrum ($CDCl_3$) showed a two proton multiplet centered at δ5.65, a one proton multiplet at 3.95, a three proton singlet at 3.24, a one proton broad multiplet at 2.79, and a complex five proton multiplet from 2.48 to 0.58. The mass spectrum (70 eV) showed peaks at m/e (rel. intensity) 136 (23.0), 121 (28.5), 105 (100), 91 (55.1), 78 (74.5), and 58 (71.2).

3) *endo*-6-Chlorotricyclo[3.3.0.$0^{2,8}$]oct-3-ene (97), 1.04%, 10.0 minutes. The PMR spectrum ($CDCl_3$), which agreed with an earlier literature report,[50] consisted of a two proton

multiplet at δ5.70, a one proton octet at 4.28, a one proton multiplet at 3.24, and a complex five proton multiplet from 2.57 to 1.34. The mass spectrum (70 eV) showed peaks at m/e (rel. intensity) 140 (6.5), 105 (100), 79 (27), 78 (35), and 77 (28). The spectral data were also identical to that of (97) prepared via an alterante route reported later.

4) 1-Methoxy-*endo*-6-chlorotricyclo[3.3.0.$0^{2,8}$]oct-3-ene (98), 18.9%, 24.0 minutes. The PMR spectrum ($CDCl_3$) consisted of a two proton triplet at δ5.73, a one proton multiplet at 4.37, a one proton multiplet at ca. 3.39 partially hidden by a three proton singlet at 3.29, and a complex four proton multiplet from 2.60 to 1.27. The mass spectrum (70 eV) gave peaks at m/e (rel. intensity) 170 (5.0), 135 (71.0), 108 (100), 103 (92.0), 91 (39.0), 78 (43.0), and 44 (82.2). The infrared (neat) showed absorption bands at 3050 (m), 2940 (s), 1590 (w), 1450 (s), 1395 (s), 1230 (s), 1135 (s), and 1010 (s) cm^{-1}.

Anal. Calcd. $C_9H_{11}OCl$: C, 63.34; H, 6.50; Cl, 20.78.
Found: C, 63.58; H, 6.64; Cl, 20.55.

Preparation of *syn*-8-Methoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]octane (89) from *syn*-8-Methoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene (95)

Catalytic hydrogenation (100 ml of hydrogen gas, 10% Pd/C, and 50 ml of methanol) of 0.510 gram of the unsaturated methyl ether (95) yielded 0.410 grams of crude product. After preparative glpc purification on column B, and subsequent spectral analysis, the product was identified as saturated *syn*-methyl ether (89).

Preparation of *syn*-8-Methoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]octane (89) from *endo-syn*-Tricyclo[3.2.1.$0^{2,4}$]octan-8-ol (26-OH)

The method[66] for alcohol methylation of Gross and Flamatti was followed. To a 50 ml ether solution of 1.00 gram of *syn*-alcohol (26-OH) obtained as an authentic sample,[22a] was added 6 drops of boron trifluoride etherate. An excess (persistant yellow) of distilled diazomethane/ether was then slowly added (nitrogen evolution) and the solution stirred for ca. 45 minutes. Anhydrous potassium carbonate was added to remove any boron trifluoride present, followed by filtration and solvent removal. A two component (1.41 glpc ratio) residue consisting of 0.834 gram of a yellow oil was separated via preparative glpc on column D. The more volatile major component was identified as the *syn*-methyl ether (89) by PMR, IR, mass spectral, and glpc retention time comparisons. The less volatile component was identified as starting material.

Preparation of *endo-anti*-Tricyclo[3.2.1.$0^{2,4}$]octan-8-ol (25-OH)[39]

Into a 500 ml flask fitted with a dry ice/isopropyl alcohol condenser was distilled ca. 350 ml of dry liquid ammonia to which 0.80 gram (0.115 g-atom) of cut lithium metal was added. A dry ethereal solution (12 ml) of 2.480 grams (0.0203 mole) of *endo*-ketone (70) was added dropwise to the deep blue ammonia/lithium solution and the reaction was stirred for ten hours. The reaction was quenched by the slow addition of 12 ml of absolute methanol, followed by evaporation of ammonia and the subsequent addition of 230 ml of water. The aqueous mixture was extracted with ether (6 x 50 ml) and

the combined ether fractions were washed with water (2 x 25 ml). The ether solution was dried over anhydrous magnesium sulfate, filtered and concentrated to dryness. The solid residue was dissolved in hot *n*-pentane, filtered, and cooled to yield 1.595 grams (0.0128 mole, 63.3%) of small white needles, m.p. 133.5-136.5°. Spectral and glpc analysis verified the composition to be 94.5% *anti*-alcohol (25-OH) and 5.5% *syn*-alcohol (25-OH).

Preparation of *anti*-8-Methoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]octane (90) from *endo-syn*-Tricyclo[3.2.1.$0^{2,4}$]octan-8-ol (25-OH)

To a 25 ml ether solution of 1.849 grams (0.0149 mole) of *anti*-alcohol (25-OH) was added one drop boron trifluoride etherate followed by a large excess of distilled diazomethane etherate. The reaction mixture was stirred over anhydrous potassium carbonate, filtered, and the solvent volume reduced. Collection by preparative glpc on column D at 110° gave 1.025 grams (7.42 mmole, 49.8%) of *anti*-methyl ether (90). The PMR spectrum ($CDCl_3$) consisted of a one proton broad multiplet at δ3.62, a three proton singlet at 3.23, a two proton multiplet at 2.21, and an eight proton complex from 1.80 to 0.28. The mass spectrum (70 eV) gave peaks at m/e (rel. intensity) 138 (7.0), 106 (24.5), 91 (35.0), 84 (55.0), 71 (100), and 41 (47). The calculated mass for $[C_9H_{14}O]^+$ is 138.1044 while accurate mass measurement gave 138.1046, for an error of 1.30 ppm. The infra-red (neat) gave absorption bands at 3050 (m), 2950 (s), 1460 (m), 1190 (m), 1110 (s), and 1010 (m) cm^{-1}.

Anal. Calcd. for $C_9H_{14}O$: C, 78.21; H, 10.21.

Found: C, 78.27; H, 10.25.

Reaction of *anti*-8-Methoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]octane (90) with a 4:1 Molar Ratio Aluminum Chloride/Lithium Aluminum Hydride

Into a dry 50 ml flask was placed 1.592 gram (11.94 mmole) of anhydrous aluminum chloride which was cooled with an external ice-water bath. Chilled anhydrous ether (12 ml) was slowly added, followed 10 minutes later by the addition of 0.113 gram (2.99 mmole)of lithium aluminum hydride. After an additional ten minutes of stirring, 0.825 gram (5.97 mmole) of *anti*-methyl ether (90) in 12 ml of ether was added dropwise, the ice-water bath removed, and the reaction stirred for 1.75 hours at room temperature. The reaction was then cooled and quenched with 12 ml of 10% sulfuric acid. The ether and aqueous layers were separated, the aqueous layer extracted (3 x 12 ml) with ether, and the combined ether fractions were dried over anhydrous potassium carbonate and magnesium sulfate. Most of the solvent was removed below room temperature under water aspirator pressure and the residual material separated on preparative glpc column D at 97° to yield three components.

(1) Tricyclo[3.3.0.$0^{2,8}$]octane (91), 0.185 gram (1.71 mmoles, 28.6%), 3.25 minutes. The PMR spectrum ($CDCl_3$) consisted of a two proton multiplet at δ2.53, and a ten proton complex from 2.14 to 1.00. The mass spectrum (70 eV) displayed peaks at m/e (rel. intensity) 108.(8.8), 93 (10.9),

91 (8.0), 80 (51.1), 79 (40.1), and 67 (100). The calculated mass for $[C_8H_{12}]^+$ is 108.0938, while accurate mass measurement gave 108.0939, for an error of 0.925 ppm. The infra-red (neat) showed absorption bands at 3020 (w), 2930 (s), and 2850 (m) cm^{-1}.

Anal. Calcd. C_8H_{12}: C, 88.81; H, 11.19.

Found: C, 88.79; H, 11.18.

(2) *endo*-4-Methoxytricyclo[3.3.0.$0^{2,8}$]octane (92), 0.278 gram (2.01 mmole, 33.7%), 18.5 minutes. The PMR spectrum ($CDCl_3$) consisted of a one proton sextet at δ3.75, a three proton singlet at 3.19, and a ten proton complex from 2.70 to 0.87. The mass spectrum (70 eV) showed peaks at m/e (rel. intensity) 38 (3.0), 06 (18.0), 91 (16.0), 89 (34.0), 79 (32.0), 71 (100.0), and 67 (15.0). The calculated mass for $[C_9H_{14}O]^+$ is 138.1044, while accurate mass determination gave 138.1044, for an error of 0.43 ppm. The infra-red (neat) displayed absorption bands at 3030 (m), 2940 (s), 2865 (s), 2820 (m), and 1115 (s) cm^{-1}.

Anal. Calcd for $C_9H_{14}O$: C, 78.21, H, 10.21.

Found: C, 78.06; H, 10.19.

3) *endo*-4-Chlorotricyclo[3.3.0.$0^{2,8}$]octane (93), 0.065 gram (0.459 mmole, 7.7%), 28 minutes. The PMR spectrum ($CDCl_3$) consisted of a one proton sextet at δ4.18, and a ten proton complex from 2.8 to 1.03. The mass spectrum (70 eV) gave peaks at m/e (rel. intensity) 142 (4.5), 107 (73.9), 106 (63.6), 101 (58.0), 91 (45.5), 80 (100), 79 (100), 78 (47.7), 77 (36.4), 67 (45.5), 66 (60.2), and 65 (38.1). The

calculated mass is 142.0549, while accurate mass determination gave 142.0545, for an error of -2.75 ppm.

Preparation of *endo, anti*-Tricyclo[3.2.1.$0^{2,4}$]oct-6-en-8-ol (107)

The method followed was a modification of the reported synthesis by Clarke, Frayne, and Johnson.[39] Into a 500 ml flask was placed 104 ml of 3M perchloric acid and 151 ml of tetrahydrofuran, and the solution was cooled to -5°. To this stirred soltuion was added dropwise 12.0 grams (0.0722 mole) of unsaturated dimethoxy ketal (78) and the reaction was stirred for 4 hours maintaining the temperature between -10 and -5°. The acid was neutralized with solid $NaHCO_3$ and extracted (4 x 150 ml) with chilled ether. The combined ether extracts were washed with 75 ml of saturated aq. Na_2CO_3 and 75 ml of water, followed by drying over anhydrous magnesium sulfate. The volume of the ether solution was reduced to ca. 25 ml under reduced pressure (vacuum pump) at 0°. The solution containing the intermediate *endo*-tricyclo[3.2.1.$0^{2,4}$]-oct-6-en-8-one (106) was added dropwise to a stirred solution of 9.0 grams (0.238 mole) sodium borohydride in 60 ml methanol at 0°. After stirring at 0° for 2 hours and then overnight at room temperature, the excess hydride was decomposed with saturated NH_4Cl solution. The filtrate was washed with ether (4 x 150 ml), and the combined ether fractions were washed with water (2 x 75 ml) and dried over anhydrous magnesium sulfate. The volume of solvent was reduced, and the residue subjected to preparative glpc on column D to yield 0.313

gram (2.56 mmole) of *anti*-unsaturated alcohol (107) along with the major product, *syn*-unsaturated alcohol. The spectral data were in agreement with literature values.[39]

Preparation of *anti*-8-Methoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene (101)

An excess of distilled diazomethane/ether was slowly added to a 25 ml ethereal solution of 0.295 gram of unsaturated *anti*-alcohol (107) in the presence of 3 drops of boron trifluoride etherate. The solution was treated with anhydrous sodium carbonate, filtered, and excess solvent was removed under water aspirator pressure below room temperature. The residue was subjected to preparative glpc on column D to yield 0.0754 gram of unsaturated *anti*-methyl ether (101). The PMR spectrum ($CDCl_3$) consisted of a two proton multiplet at δ5.67, a one proton multiplet at 3.62, a three proton multiplet at 1.14, and a two proton multiplet at 0.33. The mass spectrum (70 eV) gave peaks at m/e (rel. intensity) 136 (2.4), 105 (27.3), 104 (57.6), 103 (28.5), 91 (78.8), 78 (44.2), 77 (64.2), and 45 (100). The calculated mass for $[C_9H_{12}O]^{+\cdot}$ is 136.0887, while accurate mass measurement gave 136.0877, for an error of 7.35 ppm.

Reaction of *anti*-8-Methoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene (101) with 4:1 Molar Ratio Aluminum Chloride/Lithium Aluminum Hydride

Into a dry 10 ml flask, was placed 0.295 gram (2.21 mmole) of anhydrous aluminum chloride which was cooled with an external ice-water bath. Chilled ether (1.5 ml) was cautiously added followed by 0.0210 gram (0.553 mmole) of lithium aluminum

hydride. After stirring for 15 minutes, 0.0754 gram (0.553 mmole) of unsaturated *anti*-methyl ether (101) in 1.1 ml of ether was added, and the reaction was stirred at room temperature for 1.75 hours. The reaction was quenched (external cooling) with 10% sulfuric acid, the organic and aqueous layer separated, and the aqueous layer extracted with ether (2 x 2 ml). The combined ether fractions were dried over anhydrous potassium carbonate and magnesium sulfate, and the bulk of the solvent was removed cautiously on the rotary evacuator. The reaction residue was analyzed via capillary glpc on column B at 125° and gave, from the peak areas, 10.5% hydrocarbon, 46.4% *endo*-6-methoxytricyclo[3.3.0.$0^{2,8}$]oct-3-ene (96), 14.7% *endo*-6-chlorotricyclo[3.3.0.$0^{2,8}$]oct-3-ene (97), and a total of 28.4% of at least 4 unknowns, none of which were starting ether (101). Identification was made by authentic sample comparisons of retention times.

Action of 4:1 Molar Ratio Aluminum Chloride/Lithium Aluminum Hydride upon *syn*-8-Methoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene (95)

Into a dry 25 ml flask was placed 0.557 gram (4.18 mmole) of anhydrous aluminum chloride which was cooled with an external ice-water bath. Chilled ether (4.1 ml) was added cautiously, followed by 0.040 gram (1.044 mmoles) of lithium aluminum hydride. After stirring for 10 minutes 0.2844 gram (2.088 mmoles) of unsaturated *syn*-methyl ether (95) dissolved in 4.1 ml of ether was added cautiously. The reaction was stirred at room temperature for 3 hours, and then cooled and quenched with 10% sulfuric acid. After extraction with ether

(2 x 4 ml) and drying with anhydrous potassium carbonate and magnesium sulfate, most of the solvent was removed at below room temperature. Analysis via capillary glpc on column B at 120° showed that the *syn*-ether was effectively inert under the reaction conditions and time, in that 93% of the ether was recovered. There was an unidentified hydrocarbon (6%) and a trace (1%) of an unidentified component with relatively long retention time.

Preparation of *endo*-6-chlorotricyclo[3.3.0.$0^{2,4}$]oct-3-ene (97)

The general method of Breslow was employed.[58] To an ice-cold suspension of 12.00 grams (0.0445 mole) of cyclopentadienylthallium in 600 ml of dry dry methylene chloride were added 5.30 grams (0.0397 mole) of *n*-chlorosuccinimide. The reaction was stirred under nitrogen for one hour, after which the suspension was quickly filtered four times through celite. The filtrate was transferred to the flask containing about 75 ml of petroleum ether through which cyclopropene had been bubbled for about 2 hours at -78° (acetone/dry-ice bath). Cyclopropene was continuously passed through the solution for another 10 hours at -78°. The resulting solution was dried over anhydrous magnesium sulfate, and solvent was removed on the rotary evacuator to yield a residual orange oil. Vacuum distillation (b.p. 54.0-57.0°/2.8 mm) gave 1.399 grams (9.95 mmole, 25.1%) of a pale yellow oil. Analytical glpc on column A at 90° revealed the presence of three minor and one major fraction. Separation and purification was accomplished via preparative glpc on column C at 107°. The first fraction

(1.25 min., 2.2%) gave an ambiguous PMR, while combined glpc/mass spectral analysis on 5' SE-30 at 100 (70 eV) showed a two component fraction: 1) 122 (25.0), 81 (100.0), and 53 (27.0); 2) 146 (10.5), 139 (67.0), 103 (100.0), and 77 (51.0). The second fraction (1.50 min., 6.1%) gave a PMR spectrum ($CDCl_3$) which consisted of a two proton doublet at δ5.80, a braod one proton multiplet at 2.77, a one proton quartet at 2.38, a one proton multiplet at ca. 2.04, a two proton multiplet at 1.63, and a two proton complex centered at ca. 0.68. The glpc/mass spectrum (70 eV) gave peaks at m/e (rel. intensity) 140 (5.0), 112 (39.0), 105 (100.0), 79 (63.0), and 77 (74.5). On the basis of this data, 1-chloro-*endo*-tricyclo[3.2.1.$0^{2,4}$] oct-6-ene (123) appears to be a reasonable structure assignment. The third fraction (2.25 min., 8.0%) gave a PMR spectrum ($CDCl_3$) which consisted of a two proton triplet at δ5.81, a one proton multiplet at 4.04, a two proton multiplet at 2.82, a two proton multiplet at 1.62, and a two proton multiplet at 0.78. The glpc/mass spectrum (70 eV) gave peaks at 140 (2.5), 105 (100.0), 91 (20.0), 79 (25.0), 78 (27.0), and 77 (24.5). *Syn*-8-chloro-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene (122) appears to be a reasonable strucutre for the third fraction. The major component (3.25 min., 83.7%) gave a PMR spectrum ($CDCl_3$) which revealed a two proton multiplet at δ5.70, a one proton octet at 4.28, a one proton multiplet at 3.24, and a complex five proton multiplet from 2.57 to 1.34. The mass spectrum (70 eV) gave peaks at 140 (6.5), 105 (100), 79 (27), 78 (35), and 77 (28). The infra-red (neat) gave absorption

bands at 3050 (s), 2950 (s), 2770 (m), 1595 (m), 1450 (s), 1350 (s), 1210 (s), and 1030 (s).cm^{-1}. Spectral data were in agreement with previously reported data[50] for (97).

Preparation of 1-Methoxy-*endo*-6-Chlorotricyclo[3.3.0.$0^{2,8}$]oct-3-ene (98), Utilizing an 8:1 Molar Ratio of Aluminum Chloride/Lithium Aluminum Hydride

Into a dry 500 ml flask was added 11.62 grams (0.0872 mole) of anhydrous aluminum chloride followed by cooling with an external ice-water bath. Chilled anhydrous diethyl ether (108 ml) was cautiously added and the solution was stirred under the protection of a drying tube for 15 minutes. Lithium aluminum hydride (0.2068 gram, 5.45 mmoles) was then added with continued stirring for another 20 minutes. A solution of 7.246 grams (0.0436 mole) of the unsaturated dimethyl ketal (78) in 108 ml of ether was added dropwise to the mixed hydride reagent resulting in a light red color upon completion of the addition. The ice-water bath was removed and the reaction was stirred at room temperature for 2 hours. The red-brown reaction mixture was again cooled, followed by cautious quenching with 108 ml of 10% sulfuric acid, causing the ether and aqueous layer to separate. The aqueous layer was extracted with ether (3 x 100 ml), and the combined ether fractions were dried over anhydrous magnesium sulfate and potassium carbonate. Solvent was removed, and the oily residue was vaccum distilled (b.p. 47.47.5°/0.5mm) to yield 5.3408 grams (0.0313 mole, 71.8%) of glpc pure rearranged unsaturated methoxy chloride (98).

Preparation of 1-Ethoxy-*endo*-6-chlorotricyclo[3.3.0.$0^{2,8}$]oct-3-ene (114)

The procedure used for the preparation of the unsaturated methoxy analog (98) was followed, using the following quantities: 5.50 grams (41.2 mmole) of anhydrous aluminum chloride with 50 ml of ether; 0.098 gram (2.58 mmole) of lithium aluminum hydride; 4.0 grams (20.6 mmol) of unsaturated diethyl ketal in 50 ml of ether; and 50 ml of 10% sulfuric acid for quenching. Vacuum distillation (b.p. 57.5-60.0°/0.75 mm) yielded 2.733 grams (0.0148 mole, 71.8%) of a colorless oil. The analytical sample was collected via preparative glpc on column D at 150° (10 min.). The PMR spectrum ($CDCl_3$) consisted of a two proton triplet at δ5.73, a one proton octet at 4.42, a two proton quartet centered at 3.54, a one proton multiplet at 3.40, a four proton complex from 2.63 to 1.47, and a three proton triplet at 1.19. The mass spectrum (70 eV) gave peaks at m/e (rel. intensity) 184 (1.0), 122 (10.2), 108 (8.5), 94 (17.5), 91 (8.7), 59 (10.2), 58 (23.8), and 44 (100). The infra-red (neat) gave absorption bands at 3050 (w), 2975 (s), 2940 (m), 1385 (s), and 1140 (s) cm^{-1}.

Anal. Calcd. for $C_{10}H_{13}OCl$: C, 65.04; H, 7.09; Cl, 19.20.

Found: C, 65.34; H, 7.14; Cl, 19.13.

Preparation of 1-Methoxy-*endo*-4-chlorotricyclo[3.3.0.$0^{2,8}$]-octane (108) Utilizing an 8:1 Molar Ratio of Aluminum Chloride/Lithium Aluminum Hydride

The procedure followed was identical with the previously described preparation of the unsaturated rearranged chloride (98). The following components and quantities were used: 12.00 grams (0.090 mole) of anhydrous aluminum chloride in

113 ml ether; 0.427 gram (0.011 mole) of lithium aluminum hydride; 7.570 grams (0.0450 mole) of saturated methoxy ketal (69) in 113 ml of ether; and 113 ml of 10% sulfuric acid for quenching. Vacuum distillation (b.p. 68-72°/1.45 mm) produced 6.30 grams (0.0635 mole, 81.1%) of colorless product. The analytic sample was collected by preparative glpc on column D at 140° and capillary glpc analysis on column B at 140° demonstrated the analytical sample to be 88.5% pure, with three minor components (7.7, 1.7, 2.1%) of slightly shorter retention time. The PMR spectrum ($CDCl_3$) consisted of a one proton octet at δ4.40, a three proton singlet at 3.35, and a nine proton complex from 3.02 to 1.13. The mass spectrum (70 eV) gave peaks at m/e (rel. intentsity) 172 (1.5), 137 (35.5), and 109 (100). The calculated mass for $[C_9H_{13}OCl]^+$ is 172.0655, while accurate mass measurement gave 172.0643, for an error -6.92 ppm. The infra-red (neat) gave absorption bands at 3040 (w), 2960 (s), 2875 (m), 1450 (s), 1260 (s), and 1130 (s) cm^{-1}.

Anal. Calcd. for $C_9H_{13}OCl$: C, 62.61; H, 7.59; Cl, 20.54.
Found: C, 62.85; H, 7.66; Cl, 20.41.

Preparation of 1-Ethoxy-*endo*-4-chlorotricyclo[3.3.0.$0^{2,8}$]-octane (117) and *syn*-8-Ethoxy-*endo*-tricyclo[3.2.1.$0^{2,4}$]octane Utilizing an 8:1 Molar Ratio of Aluminum Chloride/Lithium Aluminum Hydride

The procedure followed was identical with the previously described preparation of the unsaturated rearranged chloride (98). The following components and quantities were used: 2.646 grams (19.8 mmole) of anhydrous aluminum chloride in

28 ml of ether; 0.942 gram (2.48 mmole) of lithium aluminum hydride; 1.948 grams (9.92 mmole) of saturated diethoxy ketal dissolved in 28 ml of ether; and 30 ml of 10% sulfuric acid for quenching. Preparative glpc on column O at 145° gave two analytically pure components, the first (3.5 min) being 0.241 gram (1.58 mmoles, 16.0%) of *syn*-8-ethoxy tricyclo[3.2.1.$0^{2,4}$]-octane as a colorless oil. The PMR spectrum ($CDCl_3$) exhibited a one proton multiplet at δ3.93, a two proton quartet at 3.51, a two proton broad multiplet at 2.18, and an eleven proton complex from 1.70 to 0.76 which includes a three proton triplet at 1.24. The mass spectrum (70 eV) gave peaks at m/e (rel. intensity) 98 (59.0), 85 (84.0), 70 (46.0), and 57 (100). The calculated mass for $[C_{10}H_{16}O]^+$ is 152.1200, while accurate mass determination gave 152.1201, for an error of 0.20 ppm. The infra-red (neat) gave absorption bands at 2975 (s), 2880 (m), 1460 (m), 1145 (s), and 1040 (m) cm^{-1}.

Anal. Calcd. for $C_{10}H_{16}O$: C, 78.89; H, 10.60.
Found: C, 78.72; H, 10.63.

The second component isolated by preparative glpc (11 min.) was 0.703 gram (3.77 mmoles; 38%) of the saturated rearranged ethoxy chloride (117). The PMR spectrum ($CDCl_3$) displayed a one proton octet at δ4.41, a two proton quartet at 3.57, and an eleven proton complex from 3.02 to 1.03 which includes a three proton triplet at 1.20. The mass spectrum (70 eV) gave peaks at m/e (rel. intensity) 151 (46.0), 124 (100.0), and 96 (22.5). The calculated mass for $[C_{10}H_{15}OCl]^+$ is

186.0811, while accurate mass measurement gave 186.0823, for an error of 6.88 ppm.

Anal. Calcd. for $C_{10}H_{15}OCl$: C, 64.33; H, 8.10; Cl, 19.00.
Found: C, 64.50; H, 8.15; Cl, 18.89.

Preparation of 1-Methoxytricyclo[3.3.0.$0^{2,8}$]oct-3-ene (109) from 1-Methoxy-*endo*-6-chlorotricyclo[3.3.0.$0^{2,8}$]oct-3-ene (98)

A 25 ml flask was charged with 5 ml of dry tetrahydrofuran, 2 ml of *tert*-butanol, 0.910 gram (5.33 mmole) of unsaturated methoxy chloride (98), and 0.61 gram (26.7 mg-atom) of chopped sodium metal. The mixture was stirred and heated to a gentle reflux under nitrogen for a 12 hour period, followed by cooling to room temperature and removal of excess sodium. Water (15 ml) was added, the reaction mixture extracted with ether (2 x 15 ml), and the combined ether fractions were dried over anhydrous magnesium sulfate. Most of the solvent was removed under water aspirator pressure at slightly below room temperature. The residue was submitted to preparative glpc on column D at 95° (7 min.) and yielded 0.3205 gram (2.35 mmole, 44.2%) of a pale yellow product. The PMR spectrum ($CDCl_3$) consisted of a two proton triplet at δ5.53, a three proton singlet at 3.33, a one proton broad multiplet at 3.13, and a six proton complex from 2.40 to 1.22. The mass spectrum (70 eV) exhibited peaks at m/e (rel. intensity) 136 (10.0), 104 (100), 103 (67.0), 78 (58.0), 77 (26.0), and 51 (26.0). The calculated mass for $[C_9H_{12}O]^+$ is 136.0887, while accurate mass measurement gave 136.0888, for an error or 4.85 ppm. The infra-red (neat) gave absorption bands 3050 (m), 2930 (s),

2869 (m), 2825 (m), 1590 (w), 1450 (s), 1230 (s), 1135 (s), 925 (s), and 840 (s) cm^{-1}.

Anal. Calcd. for $C_9H_{12}O$: C, 79.37; H, 8.88.
Found: C, 79.20; H, 8.95.

Preparation of 1-Methoxytricyclo[3.3.0.$0^{2,8}$]octane (110) from 1-Methoxy-*endo*-4- chlorotricyclo[3.3.0.$0^{2,8}$]octane (108)

Into a 25 ml flask was placed 5 ml of dry tetrahydrofuran, 2 ml of *tert*-butanol, and 0.920 gram (5.33 mmole) of saturated methoxy chloride (108). Chopped sodium (0.61 gram, 2.67 mg-atom) was added and the mixture was stirred under a gentle reflux and nitrogen cover for 13 hours. The reaction was cooled to room temperature, the excess sodium removed, and 15 ml of water added. Extraction with ether followed, and the combined ether fractions were dried over anhydrous magnesium sulfate. The solvent was removed under water aspirator pressure below room temperature. The residue was purified via preparative glpc on column D at 95° (8 min.) to yield 0.349 gram (2.53 mmole, 47.4%) of a colorless product. The PMR spectrum ($CDCl_3$) consisted of a three proton singlet at δ3.37, a one proton broad multiplet at 2.74, and an eleven proton complex from 2.30 to 1.08. The mass spectrum (70 eV) gave peaks at m/e (rel. intensity) 138 (9.0), 110 (100, 95 (20.5), 79 (14), and 77 (15). The infra-red (neat) displayed absorption bands at 3010, (m), 2880 (s), 1440 (s), 1490 (s), 1230 (s), and 1120 (s) cm^{-1}.

Anal. Calcd. for $C_9H_{14}O$: C, 78.21; H, 10.21.
Found: C, 77.99; H, 10.17.

Preparation of 1-Methoxytricyclo[3.3.0.$0^{2,8}$]octane (110) from the Hydrogenation of 1-Methoxytricyclo[3.3.0.$0^{2,8}$]oct-3-ene (109)

The procedure followed for the reduction was analogous to that of Garbisch.[67] Into a 50 ml flask equipped with a water condenser and nitrogen cover was placed 30 ml of glyme, 3.0 grams (16.1 mmole) of *p*-toluenesulfonylhydrazine, 3.0 grams (29.6 mmole) of triethylamine, and 0.570 gram (4.19 mmole) of 1-methoxytricyclo[3.3.0.$0^{2,8}$]oct-3-ene (109). The reaction was stirred at 84° for four days, followed subsequently by cooling to just below room temperature and the addition of 30 ml of pentane. The pentane layer was separated and washed (2 x 30 ml) with 5% sulfuric acid, 5% sodium hydroxide, and water. The organic fraction was dried over anhydrous magnesium sulfate, and the solvent removed under water aspirator pressure at below room temperature. The residue was purified by preparative glpc on column D to yield 0.287 gram (2.08 mmole, 49.6%) of a colorless liquid whose spectra were identical with the previously prepared 1-methoxytricyclo[3.3.0.$0^{2,8}$]octane (110).

Solvolysis of 1-Methoxy-*endo*-4-chlorotricyclo[3.3.0.$0^{2,8}$]-octane (108) in Aqueous Ethanol

Into a glass tube was placed 5 ml of 60% aqueous ethanol (v/v), 0.0899 gram (0.521 mmole) of saturated methoxy chloride (108), and 0.102 gram (0.739 mmole) anhydrous potassium carbonate. The tube was then sealed under vacuum and heated in an oil bath for 19 hours at 100°. After being cooled, the tube was opened and 4 ml of a standard pentane solution of unsaturated dimethoxy ketal (78) was added to the contents,

followed by 4 ml of water. The layers were separated, and the aqueous layer extracted with pentane (2 x 4 ml). The combined pentane fractions were dried over anhydrous sodium sulfate and the volume of solvent reduced under water aspirator pressure. Analysis of the reaction mixture on capillary column B gave a yield of 0.0366 gram (0.299 mmole, 68.1%) of tricyclic ketone (70) and 0.0314 gram (0.172 mmole, 19.2%) of the epimeric saturated ethoxy-methoxy ketals (115) and (116). Isolation of these products from a scaled up reaction was accomplished via preparative glpc on column D at 130°. The identity of the ketone was verified by spectral comparison with authentic ketone (70). The *anti*-ethoxy saturated ketal (115) was identified as the major component (96.0%) and the *anti*-methoxy saturated ketal (116) was determined to be the minor component (4.0%) of the ketal fraction by the respective PMR methoxyl signals at δ3.33 and 3.22. The PMR spectrum ($CDCl_3$) of the ketal fraction consisted of a two proton quartet at δ3.47, a three proton singlet at 3.33, a two proton multiplet at 2.13, and an eleven proton complex from 1.78 to 0.52, which includes a three proton triplet at 1.18. The mass spectrum (70 eV) consisted of peaks at m/e (rel. intensity) 182 (1.0), 115 (100), 87 (92.0), 69 (32), 55 (32.5), and 44 (46.0). The calculated mass for $[C_{11}H_{18}O_2]^{\cdot+}$ is 182.1306, while accurate mass determination gave 182.1309, for an error of 1.81 ppm.

Solvolysis of 1-Ethoxy-*endo*-4-chlorotricyclo[3.3.0.$0^{2,8}$]-octane (117) in Aqueous Methanol

A glass tube was charged with 0.5631 gram (3.016 mmoles)

of saturated ethoxy chloride (117), 0.6253 gram (4.525 mmoles) of anhydrous potassium carbonate, and 30 ml of 70% aqueous methanol (v/v). The tube was sealed under vacuum and heated for 27 hours at 100°, followed by cooling and the addition of 30 ml of water and 30 ml of *n*-pentane to the contents. The separated aqueous layer was extracted (2 x 30 ml) with *n*-pentane and the combined organic fractions were dried over anhydrous sodium sulfate. After solvent removal under water aspirator pressure, the residue was separated into its pure components by preparative glpc on column D at 150°. Collection of the first fraction (6 min.) yielded 0.1488 gram (0.816 mmole, 27.1%) of the mixed saturated ketals, (116) and (115), which was determined by PMR integration of the respective methoxyl signals (δ3.22 and 3.33) to consist of 96.3% *anti*-methoxy saturated ketal (116) and 3.7 of *anti*-ethoxy saturated ketal (115). The PMR spectrum ($CDCl_3$) consisted of a two proton quartet at δ3.59, a three proton singlet at 3.22, a two proton multiplet at 2.12, a complex of eleven protons from 1.84 to 0.51, which includes a three proton triplet at 1.24. The mass spectrum (70 eV) gave peaks at m/e (rel. intensity) 115 (100.0), 87 (89.1), and 55 (20.0). The calculated mass for $[C_{11}H_{18}O_1]^{\cdot +}$ is 182.1306, while accurate mass determination gave an error of 9.17 ppm. The second fraction (10 min.) gave 0.2627 gram (2.15 mmole, 71.3%) of the tricyclic ketone (70) as identified by spectral analysis.

Solvolysis of 1-Methoxy-*endo*-6-chlorotricyclo [3.3.0.$0^{2,8}$] oct-3-ene (98) in Aqueous Ethanol

A glass tube was sealed under vacuum containing 5 ml of

60% aqueous ethanol (v/v), 0.07559 gram (0.443 mmole) of unsaturated methoxy chloride (98), and 0.0940 gram (0.680 mmole) of anhydrous potassium carbonate. After heating in an oil bath at 104° for 10 hours, the cooled tube was opened and a standard solution of 1,2,4-trimethylbenzene and saturated methoxy ketal was added directly to the reaction solution. Water (4 ml) and *n*-pentane (4 ml) were then added, the organic and aqueous layers separated, and the aqueous layer was extracted with *n*-pentane (2 x 4 ml). The combined pentane fractions were dried over anhydrous sodium sulfate, and the volume of solvent was reduced under water aspirator pressure at below room temperature. Assuming a response factor of unity for the respective products and standards, capillary glpc analysis on column B gave 0.02123 gram (0.230 mmole, 53.6%) cycloheptatriene and 0.01668 gram (0.0925 mmole, 21.5%) of a mixture of the epimeric methoxy-ethoxy unsaturated ketals (112) and (113). Isolation of these products from a scaled up reaction was accomplished via preparative glpc on column D. The identity of cycloheptatriene was verified by spectral comparison with an authentic sample (Aldrich). The *anti*-ethoxy-unsaturated ketal (112) was identified as the major component (89.2%) and *anti*-methoxy unsaturated ketal (113) was determined to be the minor component (10.8%) of the mixed ketal fraction as demonstrated by integration of the respective methoxyl signals (δ3.27 and 3.13) in the PMR. The PMR spectrum ($CDCl_3$) of the *anti*-ethoxy ketal gave a quartet at 3.38, a three proton singlet at 3.27, a two

proton multiplet at 2.86, an obscured two proton multiplet at ca. 1.24, a three proton triplet at 1.13, and a two proton multiplet at ca. 0.47. The mass spectrum (70 eV) displayed peaks at m/e (rel. intensity) 180 (4.5), 122 (41.0), 94 (78.5), 91 (53.5), 44 (100), and 40 (66.5). The calculated mass for $[C_{11}H_{16}O_2]^{+\cdot}$ is 180.1149, while accurate mass measurement gave 180.1154, for an error of 2.66 ppm.

Solvolysis of 1-Ethoxy-*endo*-6-chlorotricyclo[3.3.0.$0^{2,8}$]-oct-3-ene (114) in Aqueous Methanol

Into a Carious tube was placed 30 ml of 70% aqueous methanol (v/v), 0.561 gram (4.06 mmole) of anhydrous potassium carbonate, and 0.500 gram (2.71 mmole) of unsaturated ethoxy chloride. The tube was sealed and placed in an oil bath at 104° for 24 hours. After cooling, the tube was opened and the contents added to 30 ml of water and 30 ml of *n*-pentane. The pentane and aqueous layers were separated, and the aqueous layer was extracted with pentane (2 x 30 ml). The combined pentane fractions were dried over anhydrous sodium sulfate and most of the pentane was removed under water aspirator pressure at slightly below room temperature. The residue was passed through preparative glpc column D at 130° (11 min.) to yield 0.1706 gram (0.947 mmole, 34.9%) of a colorless liquid consisting of 86.9% of *anti*-methoxy ketal (113) and 13.1% of *anti*-ethoxy ketal (112) as determined from the respective methoxy signals (δ3.13 and 3.27) in the PMR spectrum. The PMR spectrum consisted of a two proton triplet at δ5.70, a two proton quartet at 3.53, a three proton singlet at 3.13,

a two proton multiplet at 2.87, an obscured two proton multiplet at ca. 1.26, a three proton triplet at 1.22, and a two proton multiplet at 0.48. The mass spectrum (70 eV) gave peaks at m/e (rel. intensity) 180 (1.2), 94 (17.6), 91 (23.5), and 44 (100). The calculated mass for $[C_{11}H_{16}O_2]^{+}$ is 180.1149, while accurate mass determination gave 180.1154, for an error of 2.66 ppm.

Anal. Calcd. for $C_{11}H_{16}O_2$: C, 73.30; H, 8.95.
Found: C, 73.15; H, 9.00.

Reaction of 1-Methoxy-*endo*-4-chlorotricyclo[3.3.0.$0^{2,8}$]octane (108) with Methanol in the Presence of Silver (I) Perchlorate

To a solution of 3 ml of dry acetone and 0.5 ml of absolute methanol was added 0.2808 gram (1.63 mmole) of saturated methoxy chloride (108). The addition of 0.348 gram (1.68 mmole) of silver perchlorate followed and there immediately incurred a chalky precipitate. After stirring for thirty minutes, the reaction mixture was filtered through a plug of basic alumina with elution by 20 ml of dry acetone. Removal of solvent gave 0.252 gram of a yellow residue which showed two major products upon capillary glpc analysis on column B at 136°. After separation via preparative glpc on column D, the more volatile component (34.7% peak area) produced a PMR spectrum ($CDCl_3$) which had a two proton broad triplet at δ5.75, a three proton singlet at 3.66, and a nine proton complex from 2.82 to 1.21. The infra-red (neat) gave absorption bands at 3020 (m), 2940 (s), 2840 (s), 1740 (s), 1435 (s), 1200 (s), and 1160 (s) cm^{-1}. The above data indicated methyl-

4-cycloheptane-1-carboxylate (118) as the structure of the first component. The second major component (30.7% peak area) gave spectral data entirely consistent with tricyclic ketone (70).

Preparation of Methyl 4-cycloheptane-1-carboxylate (118)

To a 15 ml ether solution of 0.6939 gram (4.95 mmole) of 4-cycloheptene-1-carboxylic acid (Aldrich) was added distilled ethereal diazomethane until the orange color of the diazomethane persisted and nitrogen evolution ceased. Excess solvent was removed under water aspirator pressure, and 0.400 gram (2.59 mmole, 52.4%) of the methyl 4-cycloheptene-1-carboxylate (118) was collected on column D at 130°. Spectral data were in agreement with the literature values.[56]

Reduction of *endo*-Tricyclo[3.2.1.$0^{2,4}$]octan-8-one (70) with Lithium Tri-*sec*-butylborohydride

Preparation of reagents was adapted from the procedures of Hennion et al.[68a] and Brown.[68b,c] In a dry box, 58 ml (0.03 mole) of 0.519 M lithium aluminum hydride dissovled in tetrahydrofuran were placed in a 100 ml flask, cooled to 0°, followed by the slow addition of 0.91 ml (0.0225 mole) of absolute methanol with venting of evolved hydrogen gas. Tris-*sec*-butyl borane (6.4 ml, 0.03 mole) was added and stirring continued at room temperature for 25 minutes, followed by cooling to -78°, and the dropwise addition of .985 gram (7.34 mmole) of ketone (70). The reaction was stirred at -78° for 2.5 hours, and subsequently was stirred overnight at room temperature. On

work-up, the excess hydride was quenched with 20 ml water, 7.5 ml of 10% sodium hydroxide, and finally 9 ml of 30% hydrogen peroxide (exothermic reaction kept just below tetrahydrofuran reflux). The mixture was stirred for an additional hour, and 125 ml more of water was added. The solids present were filtered off and washed with ether, and the filtrate was extracted with ether (3 x 50 ml). The combined ether fractions were dried over anhydrous magnesium sulfate, and the solvent was removed to yield 0.5028 gram (55.2%) of crude product. Analysis of the reaction residue by capillary glpc column B demonstrated the composition to be 90.5% *endo-syn*-tricyclo-[3.2.1.$0^{2,4}$]octan-8-ol (26-OH) and 9.5% *endo-anti*-tricyclo-[3.2.1.$0^{2,4}$]octan-8-ol (25-OH).

Reduction of *endo*-Tricyclo[3.2.1.$0^{2,4}$]octan-8-one (70) with Polymethylhydrogen Siloxane

The method of Lipowitz and Bowman[69] was followed. Into a 10 ml flask was placed 0.510 gram (4.1 mmole) of ketone (70), 0.104 gram of tetrabutyldiacetoxytin oxide dimer (DBATO) and 3 ml of anhydrous ethanol. The flask was heated to 80°, and 0.292 gram (4.59 meq.) polymethylhydrogen siloxane, or PMHS, was added dropwise over a period of 1.25 hours to prevent premature gelation. Following the addition, the reaction was stirred at 80° for 1.5 hours, with the subsequent addition of 3.5 ml water, and further heating for another 1.5 hours. After cooling, solids were filtered off and washed with ether, and the filtrate extracted with ether (3 x 5 ml). The combined ether fractions were dried over anhydrous magnesium

sulfate and the volume of solvent reduced. Capillary glpc analysis on column B of the reaction mixture revealed the presence of 63.0% *syn*-alcohol (26)-OH and 37.0% of the *anti*-alcohol (25)-OH. Complete removal of solvent yielded 0.410 gram of the crude alcohol mixture.

Preparation of 1,2,3,4,5-Pentachlorocyclopentadiene

The method of McBee[70] was employed. A solution of 136.5 grams (0.5 mole) of hexachlorocyclopentadiene in 50 ml of acetone was placed in a 500 ml flask. The flask was cooled in an ice bath and 113 grams (0.5 mole) of stannous chloride dihydrate in 200 ml of acetone was added over a period of 20 minutes, the reaction temperature reaching a maximum of 40°. The color progressed from pale yellow to orange to brown. After the addition was complete, the reaction was stirred for 35 minutes with the ice bath removed. The mixture was poured into 300 ml water and extracted with carbon tetrachloride (2 x 150 ml), and the combined carbon tetrachloride fractions were dried over anhydrous magnesium sulfate. The solvent was removed under water aspirator pressure with the aid of a warm-water bath, and the residue was vacuum distilled (b.p. 85.5-89.5°/2.5 mm) to yield 64.2 grams (0.269 mole, 53.9%) of a pale yellow product. Spectral data agreed with the literature.[70]

Preparation of Octachloro-5-methylcyclopentadiene

The method of McBee was followed.[70] To a 270 ml carbon tetrachloride solution of 64.2 grams (0.269 mole) of 1,2,3,4,5-pentachlorocyclopentadiene was added, all at once, 6.75 grams

(0.506 mole) of anhydrous aluminum chloride. The reaction was stirred at 75° for 2 hours (black in color), cooled, and added to 200 ml of water. The organic and aqueous layers were separated and the aqueous layer was extracted (3 x 100 ml) with carbon tetrachloride. The combined carbon tetrachloride fractions were dried over anhydrous magnesium sulfate and the solvent was removed under water aspirator pressure with the aid of a warm-water bath. Two recrystallizations (hot carbon tetrachloride) of the brown residue gave 43.2 grams (0.121 moles, 45.1%) of pale yellow crystals, m.p. 92-93.5° (lit.[70] 93.5-94°). Spectral data were in agreement with the literature.

Preparation of Hexachlorofulvene (128)

The method of McBee[70] was followed. To a solution of 42.5 grams (0.119 mole) of octachloro-5-methylcyclopentadiene in 180 ml of hexane was added dropwise, under nitrogen, 20.8 grams (0.125 mole) of triethylphosphite in 18 ml of hexane. The reagent was added at a rate slow enough to maintain a temperature below 25°, and produced a deepening red color. The reaction was stirred for twenty minutes following the addition, and the solvent was removed on a rotary evacuator. The remaining solid was recrystallized from hot carbon tetrachloride, yielding 24.7 grams (0.0867 mole, 72.9%) of dark red needles, m.p. 150.0-151.5° (lit.[70] 153-154°). The infra-red spectrum was in agreement with that in the literature.[70] The mass spectrum (70 eV) gave peaks at m/e (rel. intensity) 290 (8.8), 288 (34.3), 286 (80.4), 284 (100.0), 286 (52.0), and 249 (35.3).

The Addition of Cyclopropene to Hexachlorofulvene (128)

Cyclopropene was bubbled through a stirred solution of 4.988 grams (0.0175 mole) of (128) in 250 ml of petroleum ether (20-40) for 36 hours, the color changing from an initial red to light orange-yellow. After the solvent was removed, the orange residue was recrystallized from anhydrous methyl alcohol to yield 2.235 grams of tan crystals. Preparative glpc on column C at 203°, followed by fractional sublimation, (134 /2mm) gave two major components.

1) 1,5,6,7-Tetrachloro-8-dichloromethylene-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene (126), 16 minutes, m.p. 143.5-145°, 80.43% relative yield. A computer analyzed PMR spectrum is given in Chapter III. The mass spectrum (70 eV) gave peaks at m/e (rel. intensity) 322 (1.0), 289 (55.1), 253 (89.0), 219 (95.3), 217 (100.0), 183 (49.6), and 181 (55.9). The infra-red (KBr) gave absorption bands at 3040 (w), 3030 (w), 1660 (s), 1595 (s), 1170 (s), 1050 (s), and 730 (s) cm^{-1}.

Anal. Calcd for $C_9H_4Cl_6$: C, 33.27, H, 1.24; Cl, 65.49.
Found: C, 33.38; H, 1.28; Cl, 65.38.

2) The second component appeared to be the adduct derived from the addition of cyclopropene dimer to hexachlorofulvene, m.p. 180-181.5°, 22 minutes, 14.97% relative yield. The PMR spectrum ($CDCl_3$) consisted of a two proton doublet at δ2.04, and a six proton complex from 1.13 to 0.18 The mass spectrum (70 eV) gave peaks at m/e (rel. intensity) 329 (100), 293 (53.3), 263 (91.1), 258 (91.1), 256 (97.8), and 253 (95.6). The infra-red spectrum (KBr) gave absorption

bands at 3035 (w), 3000 (m), 1655 (s), 1590 (s), 1245 (s), 1000 (s), and 765 (s). cm^{-1}.

Anal. Calcd. for $C_{12}H_8Cl_6$: C, 39.49; H, 2.21; Cl, 58.30.
Found: C, 39.61; H, 2.25; Cl, 58.15.

Preparation of 1,5,6,7-Tetrachloro-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene (127)

Cyclopropene was bubbled through a vigorously stirred solution of 0.6809 gram (3.34 mole) of 1,2,3,4-tetrachlorocyclopentadiene in petroleum ether (20-40°) for 4.5 hours. After solvent removal, the oily yellow residue was vacuum sublimed twice (74°/1 mm) to yield 0.633 gram (2.59 mmole, 77.7%) of white crystals. Preparative glpc on column C at 160° (10.5 min) gave the analytical sample, m.p. 51.5-53.0°. Computer analysis of the PMR spectrum of a 1M CCl_4 solution of (127) is given in Chapter III. The infra-red (neat) showed absorption bands at 3000 (w), 1590 (m), 1270 (s), 1230 (m), 1115 (m), 1055 (m) and 965 (s) cm^{-1}.

Anal. Calcd. for $C_8H_6Cl_4$: C, 39.38; H, 2.48; Cl, 58.14.
Found: C, 39.26; H, 2.51; Cl, 58.11.

Preparation of 1,5,6,7,8,8-Hexachloro-*endo*-tricyclo[3.2.1.$0^{2,4}$]oct-6-ene (125)

Cyclopropene was bubbled through a stirred 150 ml benzene solution of 5.0 grams (0.0183 mole) of hexachlorocyclopentadiene for 4 hours. The benzene was removed on a rotary evaporator to yield 5.3 grams (0.0169 mole, 92.6%) of a light yellow solid. Vacuum sublimation (100°/1 mm) gave a white crystaline solid, m.p. 161-163°. Computer analysis of 1M

CCl_4 solution is given in Chapter III. The infra-red (KBr) showed absorptions at 3025 (w), 3035 (w), 1600 (s), 1435 (m), 1270 (s), 1190 (s), 1025 (s), and 735 (s) cm^{-1}.

Anal. Calcd. for $C_8H_4Cl_6$: C, 30.71; H, 1.29; Cl, 68.00.

Found: C, 30.89; H, 1.35; Cl, 67.84.

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BIOGRAPHICAL SKETCH

Warren Charles Nielsen was born on January 9, 1945 in Brooklyn, New York, to Arthur and Kathleen Nielsen. After moving to Virginia and attending the public school system in Norfolk, he graduated from Granby High School in 1963. Upon completion of his undergraduate studies at Old Dominion University in 1967, he received the degree of Bachelor of Science with a major in chemistry. Mr. Nielsen entered the Graduate School at the University of Florida in the Fall of 1967 for continued study in organic chemistry, which was interrupted beginning in 1969 with two years of involuntary military service. He returned to Gainesville in 1971 to complete his graduate education, and in 1972 married the former Judith Golding. Mr. Nielsen is a member of the American Chemical Society.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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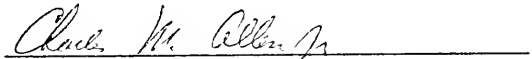

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This dissertation was submitted to the Graduate Faculty of the Department of Chemistry in the College of Arts and Sciences and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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